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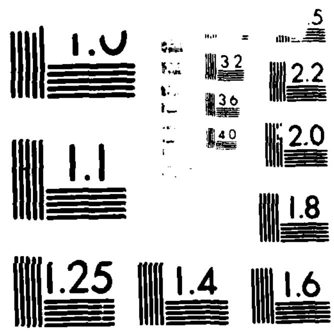
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REPORT JTCG/AS-77-D-001

JTCG/AS

GUIDEBOOK FOR PREPARATION OF AIRCRAFT SYSTEM SURVIVABILITY REQUIREMENTS FOR PROCUREMENT DOCUMENTS

Final Report

John Morrow
Robert Burris
David Watson

May 1977

Prepared for

THE JOINT LOGISTICS COMMANDERS
JOINT TECHNICAL COORDINATING GROUP
ON
AIRCRAFT SURVIVABILITY

[redacted]

FOREWORD

This report presents the results of a study performed under Contract N00123-75-C-1265 to develop and document a system procurement documentation guidebook containing standard key words, phrases, and contractual clauses establishing survivability/vulnerability (S/V) requirements applicable to DoD aircraft. The report is intended for use by all DoD systems engineering organizations responsible for relating S/V requirements in requests for procurement of aircraft and related systems.

The work was sponsored by the JTCG/AS and was accomplished by Armament Systems. Inc., Anaheim, California. Mr. George E. Moncsko, NWC Code 4083, was the Project Manager/Monitor. Armament Systems personnel responsible for the preparation of this document were Mr. John J. Morrow, Mr. Robert A. Burris, and Mr. David J. Watson.

NOTE

This guidebook was prepared by the Design Criteria and Industry Interface Subgroup of the Joint Technical Coordinating Group on Aircraft Survivability in the Joint Logistics Commanders Organization. Because the Services' aircraft survivability development programs are dynamic and changing, the report represents the best data available to the subgroup at this time. It has been coordinated and approved at the JTCG subgroup level.

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This report is intended to provide guidelines for the preparation of procurement specifications for aircraft survivability enhancement equipment, for the survivability/vulnerability (S/V) tasks associated with the procurement of a total aircraft system or its related subsystems, and also for the modification of current fleet aircraft to their related subsystems.

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1.0 INTRODUCTION

1.1 OBJECTIVE

This report is intended to provide guidelines for the preparation of procurement specifications for aircraft survivability enhancement equipment, for the survivability/vulnerability (S/V) tasks associated with the procurement of a total aircraft system or its related subsystems, and also for the modification of current fleet aircraft to their related subsystems.

1.2 APPLICABILITY

It is intended that these S/V procurement guidelines be applied to the procurement of all military aircraft, aircraft subsystems, and aircraft components which can either lose their functional capability or have their performance degraded as a result of interactions with the damage mechanisms of threat weapons. The guidelines should be applied to preliminary design programs, to research and development programs, to production programs, and to programs which will retrofit or modify existing systems.

1.3 SCOPE

These guidelines include general requirements statements for the establishment of a S/V program, requirements statements for reducing the susceptibility of the system to the threat weapons, and requirements for the reduction of vulnerability to nonnuclear, nuclear, and laser weapon effects. Requirements for S/V assessments and the verification of vulnerability levels and survival enhancement features are also included. Although nuclear and laser weapon effects are included, the major emphasis is on the reduction of susceptibility and vulnerability to conventional weapons and the establishment of the S/V program.

1.4 FORMAT AND USE

The general format of this document combines a description of the subject or problem for which a S/V procurement specification statement may be needed along with representative examples of such statements. The report format is varied to be compatible with the subject matter of the individual sections.

These guidelines present alternate language for both general requirements and specific requirements as well as alternate language for both qualitative requirements and quantitative requirements. The general and qualitative language should be used if it is desired to give the bidder or contractor flexibility to conduct trade-off studies in the development of the quantitative requirements.

The general requirements section presents procurement guidelines for establishing and maintaining a S/V program. The section is scoped to include all the elements of an aircraft development program – various elements of the program are identified and sample statements are presented. The user should compare his actual needs with the elements of this guideline and select those which are applicable. The wording of the statements should be carefully analyzed before being used in a specification. There should be no hesitancy to modify these statements to improve their applicability, scope, or wording. (This analysis and tailoring of the requirements statements applies throughout the sections of this document. These are guidelines only.)

Sections 3 through 6 apply to specific characteristics and subsystems of the aircraft and should provide assistance for all aspects of a survivability enhancement program. The requirements statements have been taken from actual procurement documents with modifications to broaden their applicability.

Sample statements referring to a threat weapon and, where applicable, its energy level(s), appear throughout the guidelines. In many cases, blanks are left in the statements and the design threat must be inserted. In other cases, these blanks were filled with representative values to assist the user in establishing magnitudes or in identifying variables. These items are either underlined or enclosed in parentheses (or both). The user of these statements must select the actual values and variables to be used, based on the employment of the system or aircraft and the threat damage mechanisms for which it is to be designed.

Where applicable and available, alternative requirements statements are presented for the same subject. Usually these are in the form of a general requirement versus a specific requirement or a qualitative requirement versus a quantitative requirement. There are also alternatives in the assessment and verification sections that represent different program philosophies and varying degrees of available detail.

Simple appendixes have been included to assist the user. These include a set of definitions of S/V terms used in the document, an unclassified listing of applicable weapon parameters, a set of definitions for kill levels (kill criteria), and the identification of the documents used in the preparation of these guidelines.

The most important factor that can be stressed here is the need to modify these requirements statements to meet the needs of the program.

2.0 GENERAL SURVIVABILITY/VULNERABILITY REQUIREMENTS

There are several general requirements statements that should be included in the survivability specification. These include:

a. A statement of the scope of the survivability specification.

b. A general requirements statement or statement of the objective of the survivability specifications.

c. A definition of the required S/V program.

d. A statement that defines the required S/V organization for the procurement.

e. An identification of the required S/V plans, procedures, and program reviews.

f. A general specification of the threats to be considered in the program.

g. An identification of the kill criteria to be considered in the program.

h. Applicable reference documents.

Each of these subjects is discussed in the following paragraphs and each discussion includes a representative paragraph. Each representative paragraph is provided to serve as a guideline only, and is to be used only after appropriate tailoring or modification to meet the needs of the specific procurement specification for survivable aircraft and aircraft systems.

2.1 SCOPE STATEMENT

The scope statement sets the general limits of the system survivability procurement and should contain the following types of information:

a. A specific reference to the procurement program to which the specification applies.

b. The procurement document(s) which interfaces with the specification.

c. The extent of the application of the program to nuclear, nonnuclear, and other types of threat weapons and survivability enhancement considerations.

d. The program elements included in the specification.

e. The existence of requirements for trade-off studies or cost-effectiveness analyses in the process of selecting survivability enhancement features.

A representative scope statement is as follows:

"This document establishes the survivability/vulnerability (S/V) program requirements in the design and development of the (aircraft, aircraft subsystem, or component). It is to be used in conjunction with the statement of work for this procurement (and, if not actually a part of it, the system specification). The requirements of this document cover both nuclear and nonnuclear weapon effects protection together with other survivability enhancement elements. This specification includes the requirements for a S/V program, a S/V program organization, S/V plans, procedures, assessments, and validations. This specification also includes the identification of the threat weapons and the survival enhancement requirements with respect to these threat weapons. Trade-off studies and cost-effectiveness analyses are specified to identify and incorporate the best survivability enhancement design features."

2.2 GENERAL REQUIREMENTS OR OBJECTIVES STATEMENT

The general requirements statement identifies the overall objectives of the S/V specifications for the procurement. It states the overall S/V requirement, the general objective of the survivability enhancements, and general requirements for ballistic protection and system redundancy.

The following are representative general requirements statements:

"The contractor shall develop and implement a Survivability/Vulnerability (S/V) Program Plan to insure proper emphasis on nuclear and nonnuclear survivability in system design, development, fabrication, and test. Emphasis is to be placed on the development of optimum quantitative requirements and sound planning for implementation of the S/V program during all phases of the system design and development. In the implementation of the S/V program, the survivability of the aircraft system shall be enhanced by the effective employment of design features that (1) minimize the observable signatures of the aircraft, (2) employ countermeasures or counter-countermeasures, (3) minimize vulnerability to nuclear and nonnuclear weapon effects, and (4) minimize vulnerability to external friendly and hostile electromagnetic environments."

The following paragraphs can be used to specify general envelopes from which protection is required.

a. Attack aircraft or aircraft exposed to surface-to-air small arms fire and antiaircraft weapons:

   "Maximum protection of the lower hemisphere of the aircraft [including ___° (above/below) the horizon] is required. Upper hemisphere vulnerability shall be minimized to the greatest extent practical, especially from HEI projectiles."

b. Aircraft exposed to an air-to-air cannot threat:

   "Maximum protection of the aircraft for all projectile trajectories from within a ___° cone about the rear of the aircraft is required. The centerline of this cone is to be on the aft projection in the direction of flight of the aircraft."

c. Aircraft exposed to air-to-air and surface-to-air missiles:

   "Maximum protection is required for fragments emanating from missile detonations at any direction from the aircraft."

The following paragraph presents a general statement of the requirements for independency and separation or isolation for the establishment of redundancy as a survivability enhancement feature.

"Redundancy of critical subsystems requires that each be independent of the other and that each subsystem be capable of performing all essential functions whenever the counterpart subsystem is incapacitated for any reason. It is also required that each subsystem be sufficiently separated or located within the aircraft so that direct ballistic impact, impact from spalled round, catastrophic mechanical failure, jamming, or fire/overtemperature do not incapacitate both a critical subsystem and its counterpart subsystems."

2.3 SURVIVABILITY/VULNERABILITY PROGRAM REQUIREMENT

This section of the S/V procurement specification establishes the requirement for the contractor to develop a program for the implementation of survivability enhancement considerations during the design and development processes.

"The prime contractor is responsible for total system survivability. This responsibility includes the provision of S/V support in the design process and continuing S/V review during the development phase of the program. The contractor will develop and implement a Survivability/Vulnerability Management Program. The program shall: (1) identify the S/V organization responsible for the conduct of the program, interfaces, and authority; (2) outline the method(s) by which the S/V program will be conducted, the relationship of the S/V program to other program tasks/events, and the funding level associated with each task in the work breakdown structure (WBS); (3) specify the procedures required for the conduct of the S/V program (e.g., implementing S/V requirements into design, program control, etc.); and (4) plan and schedule program reviews."

If the specification is for a total aircraft system, the responsibilities of the S/V interfaces between the prime contractor and the propulsion subcontractor must be established.

"The prime contractor shall coordinate with the propulsion subcontractor in order to establish a total system S/V program. Respective responsibilities for analysis and design shall be mutually established and agreed upon between the prime contractor and propulsion subcontractors. Specific attention and support should be given to the development of effective trade-offs between performance, IR signature, and smoke abatement."

2.4 SURVIVABILITY/VULNERABILITY ORGANIZATION

This paragraph in the specification describes the S/V organization that is to be established to conduct the S/V program.

"The contractor shall develop and staff a S/V organization responsible for the conduct of the S/V program. This organization shall interface with all relevant design, support, and program management activities so that the S/V requirements are effectively incorporated into the system. The relationships to each activity shall be defined. The responsibilities and authority of the S/V engineering organization shall be described to indicate its influence in the design and development program."

2.5 SURVIVABILITY/VULNERABILITY PROGRAM PLAN, PROCEDURES, REVIEWS, AND REPORTS

2.5.1 Survivability/Vulnerability Program Plan and Procedures

This section of the specification describes the requirements of the S/V Program Plan, the procedures required to implement the plan, and the establishment of S/V program reviews and reports to monitor the implementation of the plan. A representative statement of the requirement for the S/V plan is as follows:

"The contractor shall develop and implement a Survivability/Vulnerability Program Plan to assure proper emphasis on nuclear and nonnuclear survivability in system design, development, fabrication, and test. The plan shall outline the method by which the contractor proposes to conduct the program tasks for which he is responsible. The interfaces with other program tasks and events shall be clearly shown and described. Each task in the plan shall be identified with the work breakdown structure so that traceability and monitoring of funding may be accomplished. Emphasis is to be placed on the development of optimum quantitative requirements and sound planning for implementation of the S/V program during all phases of the design and development. The program plan will also include the schedule and format for the reporting of S/V data.

"The S/V Program Plan shall describe a continuing program and shall include, but not be limited to, the following procedures:

a. An organizational structure with S/V personnel at a level such that survivability enhancement and vulnerability reduction requirements and design techniques are effectively implemented throughout the design process beginning with the earliest phases of preliminary design.

b. A procedure for implementation of S/V requirements by associate contractors or subcontractors.

c. A procedure for conveying the latest S/V information, guidance, and design techniques to the design, analysis, and management activities involved in the design and development of the aircraft system, its subsystems, or components.

d. A procedure for the control and monitoring of S/V program funds and expenditures.

e. A procedure through which the designers are to provide the S/V engineering and analysis organization with the information needed for each of the program tasks including S/V assessments, trade-off studies, and cost-effectiveness analyses so that these efforts reflect the current status of the design.

f. A procedure for implementation and control of developmental, evaluation, and verification tests and analyses.

g. A continuing analytical methodology to assess S/V levels based on the specified threat. The assessments are to support survivability enhancement and vulnerability reduction design studies, trade-offs, and cost-effectiveness analyses. They are to be conducted throughout all phases of design and acquisition as an iterative process whereby quantitative S/V levels are continually updated and the current levels are available for review and evaluation at any time during the program."

2.5.2 Survivability/Vulnerability Program Reviews

"S/V Program Reviews shall be planned and scheduled to permit the prime contractor and government representatives to periodically examine the status of the S/V program, including results achieved. These formal reviews shall be at preplanned points identified in the S/V Program Plan. They shall be coordinated with overall program reviews, design reviews, inspections, etc. The prime contractor will prepare and submit at the first review a document detailing all S/V considerations which have taken place prior to the first program review.

"The program reviews shall include, to the extend applicable, the following:

a. A review of current S/V estimates and achievements for each specified threat and requirement.

b. A review of S/V design features and a comparison with system requirements.

c. An identification of problem areas or areas of noncompliance with requirements and proposed plans for correction.

d. Status and results of trade-off studies conducted for S/V engineering.

e. Mockup review of S/V design features. This shall be conducted during preliminary design reviews and critical design reviews of the system.

f. Review of all verification testing and results.

g. Procedures to assure that appropriate personnel from the S/V organization participate in the design reviews for approval of the design.

h. Identification of the principal items inhibiting S/V planned achievement and proposed solutions.

i. Status of S/V program funds, expenditures, and allocations for future tasks.

j. The documentation of the results of design reviews."

2.5.3 Reporting

Documentation of the S/V program must be called out in the procurement specification. The following is an example of such a procurement statement.

"The following S/V engineering reports shall be prepared and submitted in accordance with the contract data item descriptions and requirements:

a. S/V Program Plan.

b. S/V Procedures.

c. Mission/Threat Analysis.

d. Flight Mission Essential Functions and Subsystems/Components Identification.

e. Failure Mode and Effects Analysis.

f. Damage Mode and Effects Analysis.

g. Vulnerability Assessments.

h. Survivability Assessments.

i. System Cost-Effectiveness Analysis.

j. Design S/V Status.

The updating and resubmittal of each report shall be accomplished by the contractor as shown on the DD Form 1423."

2.6 SURVIVABILITY/VULNERABILITY TRADE-OFF STUDIES

Trade-off studies and system cost-effectiveness analyses should normally be specified to identify the best survivability design features consistent and compatible with the expected threat, mission requirements, and performance requirements of the aircraft. The procurement statement may be general or may define specific trade-offs required for the program. A typical general statement is as follows:

"Trade-off studies shall be conducted continuously during concept formulation, contract definition, engineering development, and production to identify and justify the selection of survivability enhancement features."

2.6.1 Survivability/Vulnerability Optimization Study

The following requirements statement represents an alternate way in which to specify a general S/V trade-off study:

"The contractor shall conduct a Survivability/Vulnerability Trade-off Study to optimize system survivability by a continuous evaluation to provide the best combination of system elements for the least vulnerable (most survivable) design in terms of performance, schedule, and total system cost. This study shall show the effects of variations in each significant survivability parameter varied individually so that relative effect on total system performance, schedule, and cost can be determined. The following factors shall be considered in accomplishing the trade-off studies:

a. Ballistic vulnerability reduction with respect to the basic and alternate threats.

b. Reduction of electromagnetic, infrared, radar cross section, acoustic, and visual signatures.

c. Reduction of vulnerability to external friendly and hostile electromagnetic environments.

d. Aircraft weight and performance penalties.

e. Enhancement of crashworthiness (if applicable).

f. Effect on performance, empty weight, maintainability, reliability, cost, and schedule.

"The contractor, as a result of the trade-off study, shall present the following results:

a. Recommendations and alternatives regarding optimum design.
b. Identification of those areas where it has been necessary to deviate from normally accepted design practices in order to provide occupant protection throughout the 95th percentile accident environment."

2.6.2 Subsystem Trade-off Study

Trade-off studies are particularly important when the protection concepts inherently involve significant weight or cost penalties. Perhaps the best example of this type of study is the analysis to determine the effectiveness of ballistic armor and the associated weight and cost (the required space for armor installation may also be critical) increments. The trade-off study, as shown in the following example, may involve variations in threat or in coverage.

"A comparison shall be made of armor protection alternatives for the aircrew and flight critical components. The results of this comparative study shall include weight and cost differences for each armor configuration alternative, the survivability protection provided with each design, and the performance penalties (if any) incurred with each level of protection. The baseline study for the crew station armor protection shall completely protect the crew members from the applicable damage mechanisms (blast, fragment spray, and projectile or core penetration) from all aspects with the exception of the canopy and windshield areas. The addition of armor or more armor to protect the flight critical components as well as any other components shall be considered only after all other types of vulnerability reduction have been explored."

The baseline and alternative armor configurations need to be further specified the respect to the threat projectile impact velocity (slant range), and impact obliquity design requirements.

The baseline armor configuration should provide protection against the_______projectile fired from____(feet or meters) slant range (or at an impact velocity of____feet or meters) per second and impacting at_______° obliquity. (More than one threat may be specified for the baseline configuration.)

Similar specification statements should be prepared for the threats of alternate protection configurations. The alternate protection levels may also be specified as being adaptable to in-field installation if it is shown to be desirable to provide a kit for upgrading the protection level to meet a more severe threat. A typical specification statement for such an armor approach is as follows:

"The second level of armor protection should be identical to the baseline level but must have provisions designed directly into it for increasing the protection level to defeat the______projectile impacting at____(feet or meters) per second and at____°obliquity. This increased protection capability must be able to be incorporated into the aircraft through in-field installation of additional armor, tipping plates, etc. These provisions shall include additional armor attachment points, mounting/support brackets, clearances between surrounding structure/components and the basic armor, beefed-up structural support members, etc."

An additional armor trade-off study that may be useful determines survivability protection, installed armor weight and cost, and any applicable performance increments as a function of armor protection level (protected aspect, impact velocity, obliquity, etc.). This could be specified with a paragraph such as the following:

"An armor trade-off shall be performed to determine the effect on armor protection level, weight, and cost and the effect on aircraft performance resulting from a systematic variation of the aspects from which the threat will be defeated, the impact velocity, and the limiting angle of obliquity."

All armor trade-off studies should include the following documentation requirement:

"Supporting data (including drawings, if necessary) should be provided to allow complete and thorough evaluation of the armor system. This applies to crew stations and any other areas on the air vehicle where ballistic protection is provided."

Similar trade-off and effectiveness study requirements can be written for other vulnerability reduction concepts such as foams within fuel tanks, void filler foams, self-sealing tanks and lines, redundant subsystems or components, or damage tolerant structures.

Another type of trade-off study which should be conducted is aimed at identifying survivability enhancement features which will result in a total aircraft system with balanced survivability. System vulnerability reduction, the reduction of detectables, and the employment of survivability aids are all considered in the definition of this balanced survivability design. The study should also provide justification for the selection of the survivability enhancement features.

"A trade-off study shall be performed to identify and select the vulnerability reduction features, the techniques or materials/components for the reduction of the aircraft's detectables, and the survivability aids that result in an optimum total system survivability based on mission completion requirements or total program (life cycle) costs."

An optional way to state the requirement is as follows:

"The aircraft system shall be subjected to a system cost-effectiveness analysis to support trade-off studies of candidate survivability enhancement techniques and design features as they affect mission capability and aircraft attrition. These analyses shall be used to identify the most effective survivability features to be incorporated into the design configuration. Any proposed changes of survivability features in the design shall be supported by appropriate system cost analyses. This shall include detectables (infrared, radar cross section, visual, aural) and survivability aids [i.e., electronic countermeasure (ECM), electronic counter-countermeasures (ECCM), etc.]. The analysis method shall be as specified in the aircraft systems specification and the results submitted to the procuring activity for approval."

2.7 THREAT

The survivability of an aircraft, its subsystems, and its components and the enhancement of this survivability is directly related to the design threat. The procurement specification must, as a minimum, identify the specific weapons to be considered and, where applicable, the energy levels of the threat. If a kinetic energy projectile is to be considered, the specification should identify the projectile and either the impact velocity or the slant range at impact, i.e.:

"12.7-mm API, Type B-32, Soviet, impacting at____ft/sec."

"14.5-mm API, Type B-32, M1932, Soviet, Hardened steel core at____feet slant range."

"105-grain fragment impacting at____ft/sec."

High explosive projectile should include the type of fuzing:

"23-mm HEI-T, Type OFZT, with MG-25 fuze impacting at____ft/sec."

"23-mm HEI-T, Super-quick fuzed projectile with A-23 or K-23 fuze, impacting at ____ ft/sec."

The threat definition, particularly with missiles, may consist of no more than an identification of the weapon.

Note that some subsystems may have different design threat requirements from others in the same aircraft. Also, the threats of S/V assessments and trade-off studies may be different than the design threats.

2.8 KILL CRITERIA

The kill criteria, or kill level, is the measure of the degree of performance degradation of a target or target element as a result of exposure to the threat weapon damage mechanisms. The specified kill criteria will vary depending upon aircraft type, application, and priorities. A number of criteria have, therefore, been developed to measure the degree of performance degradation. These individual criteria are defined in Appendix D.

The kill criteria may be applied to the total aircraft or to individual subsystems and components. The criteria include a set of time-based attrition kills (e.g., KK, K, A, and B), mission-related or mission-limiting measures, and measures related to the magnitude of the maintenance requirement resulting from the combat damage. There is also a kill criteria (E-kill) which denotes damage to the aircraft which will result in further damage upon landing.

Kill criteria must be selected for the procurement and might be specified as follows:

"The following kill criteria will be employed in the vulnerability assessment." (Selected criteria would then be identified along with definitions.)

2.9 REFERENCE DOCUMENTS

The survival enhancement program requires the use of standard reference documents such as regulations and standards. Those used should represent the required system or subsystem technology for the procuring agency. A typical introductory statement for applicable documents in the specification is as follows:

"The following documents of issue, in effect on the date of this specification (statement of work), form a part of this specification (statement of work) to the extent specified herein. In the event of a conflict between a document referenced herein and the contents of this specification (statement of work), the contents of this specification (statement of work) shall be considered a superseding requirement."

Report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards, is a comprehensive source for the identification of reference documents; Report JTCG/AS-74-D-002, Proposed MIL-STD-XXX, Aircraft Nonnuclear Survivability/Vulnerability Terms, defines S/V related terms; Proposed MIL-STD-XXX, Nonnuclear Survivability Program Requirements for Aircraft (JTCG/AS Task 5.1.8.X.6) will define a nonnuclear program and its requirements.

3.0 SUSCEPTIBILITY REDUCTION

Survivability is a function of two general types of variables: those that define the susceptibility of the aircraft to exposure or interaction with the threat weapon kill mechanisms, and those that define the reaction of the target to the threat weapon exposure or interaction. This section of the Survivability/Vulnerability (S/V) procurement guidelines deals with the requirements for reducing susceptibility and is subdivided into three major areas: the reduction of detectables, the employment of countermeasures, and the minimization of vulnerability to external electromagnetic environments. Each one, or a combination of the three, can be used to deny or degrade the susceptibility of the target to the threat weapons.

Each representative paragraph or sample statement in this section is provided to serve as a guideline only, and is to be used only after appropriate tailoring or modification to meet the needs of the specific procurement specification for reducing susceptibility.

3.1 DETECTABLES

The detectables include all signatures which can be used to detect and track the aircraft as a target. The selected requirements may include both signature analysis and reduction. General paragraphs for analysis and signature reduction are as follows:

"An aircraft signature analysis shall be conducted and maintained to assess the compatibility of the configuration and design features with minimum radar, infrared, visual, aural, and electromagnetic signatures of the vehicle. The results of this analysis will be used as guidance for minimizing the aircraft signature through design wherever practical.

"A signature reduction program will be conducted concurrent with the development program to ensure that the design meets the criteria contained in the signature level specification. As a minimum, the signature reduction program will develop information and data to establish and substantiate the signature levels of the aircraft."

An alternate general statement for signature reduction is:

"Effective reduction of aircraft detectables shall be accomplished for the hostile threat systems defined in the mission-threat analysis."

The latter statement, however, is ambiguous because the word "effective" is not defined.

3.1.1 Radar Cross Section

Radar fire control systems are employed by, or are an employment option of, most antiaircraft guns 23-mm or larger and many of the surface-to-air and air-to-air missiles. The radar cross section (RCS) requirements are normally specified both in terms of signature reduction and signature analysis. The analysis requirement should identify the threat weapons to be considered (usually through reference to the threat specification) and the frequencies to be investigated.

"An analysis shall be conducted to determine the radar reflectivity of the aircraft and to identify the primary sources of reflectivity. Radar signatures will be estimated for the ___ frequency bands associated with the hostile threat systems defined in the specification (statement of work). The analysis shall provide the basis for RCS reduction allocations (both for the prime contractor and associate contractors or subcontractors) as applicable. The magnitude of RCS reduction achievable on aircraft components shall be analytically determined and the contribution of each component to the radar signature of the complete aircraft shall be determined. An analysis shall be conducted to determine and reflect the further RCS reduction possible and the methods, costs, weight, volume, etc., involved in achieving these levels."

A representative RCS reduction requirements statement is as follows:

"The radar cross section signature shall be minimized for those aspect angles and frequencies associated with the hostile threat systems defined in the aircraft S/V specification and statement of work. The contractor shall clearly define his concept of design requirements, problems, and proposed solutions associated with achieving the minimum practical radar cross section (RCS) for the individual aircraft components and the complete aircraft. RCS reduction materials, components, coatings, and application techniques proposed for achieving a low radar signature shall be evaluated for structural integrity, vibration, and compatibility with the operational environment of the aircraft."

It may be desirable to identify the components/subsystems to be emphasized in the RCS reduction. Typical elements of a fixed wing aircraft are:

a. Fuselage.
b. Fuselage-wing-empennage interfaces.
c. Canopy.

d. Inlet and exhaust cavities including cavity termination.
e. Radomes, antennas.
f. External stores.

Typical elements of rotary wing aircraft are:

a. Fuselage.
b. Main rotor blades.
c. Main rotor hub.
d. Main rotor mast.
e. Tail rotor blades.
f. Tail rotor hub.
g. Tail rotor drive.
h. Cockpit canopy.
i. Landing gear.
j. Intake and exhaust ducts.
k. Fuselage-sponson interfaces.

3.1.2 Infrared Signature

Infrared (IR) signatures are used as detection and guidance sources by both air-to-air and surface-to-air missiles. They must be considered in the development of a survivable aircraft system. Like the statements on the radar cross section, the specification statements on IR signatures should cover both the analysis requirements and the requirements for signature reduction.

A typical statement of the IR analysis requirement is as follows:

"The selection of an engine cycle shall be made with consideration given to the IR signature. An analytical assessment of the IR radiation in the ___-micron bandwidth range shall then be performed. The following information and data relative to this assessment shall be developed.

a. Estimated unsuppressed radiation levels in each of the specific bandwidths for each of the primary sources, i.e., engine hot parts and exhaust plume; and for secondary source radiations such as gearboxes, oil radiators, engine cowls, solar reflection, etc.

b. The method(s) for predicting the radiation of the various sources."

The IR signature reduction requirement must address the signature of the propulsion system and any other heat sources, or areas of reflection of IR energy. A representative IR signature reduction requirement statement is:

"Techniques to reduce the infrared (IR) radiation signature in the ______-micron bandwidth shall be addressed (provide signature reduction, cost and weight increments, and performance degradations) to provide a minimal practical heat source and heat reflectivity envelope. The techniques to be employed shall address, but not be limited to, the following primary and secondary IR sources:

a. Engine hot parts.
b. Tail pipes and surfaces heated by exhaust gas impingement.
c. Exhaust plume.
d. Gearboxes and transmissions.
e. Aerodynamically heated surfaces.
f. Solar reflection.

"Based upon the assessment of the IR radiation levels of the basic aircraft, design data for IR suppression to reduce the radiation levels to those prescribed by the specification will be developed and the following information provided.

a. A description of the complete IR suppression system and total weight (including such components as tailpipes, fans, lines, shields, insulation brackets, and cowling) with the location of the system within the aerial vehicle clearly indicated by a phantom three-view drawing. The description will include the main powerplant installation including selected arrangement, shielding, and tailpipe configuration.

b. A complete tailpipe description with scale drawings showing geometry, weight, interface, cooling techniques, and materials. Heat transfer data and analysis for the selected cooling technique shall be provided with a definition of cooled area.

c. A complete description of the suppressor cooling system including type, size, lines, weight, arrangement, mass flow, pressure rise, and power required.

d. Suppression concepts for reduction of radiation from the airframe shall be defined by drawings or other techniques. An analysis of surface finishes in relation to bright sun conditions,is to be presented."

3.1.3 Visual Signature

The visual signature of the aircraft is the detection and tracking signature for small arms and machine gun type weapons and is an alternate tracking signature for several of the radar-directed weapons.

"A visual detection assessment shall be conducted to assure the following:

a. Maximized use of nonreflecting and camouflage paints to minimize detection from the ground and from the air during low altitude or nap-of-the-earth flight.

b. Engine exhaust (flame, plume, or glowing hot metal parts) is not visible to ground observers at night.

c. Use of window and windshield designs and materials to minimize the detection hazard through reflection of sun or other light sources consistent with good crew vision in daylight and darkness and minimal use of curved, highly reflective, transparent surfaces.

d. Minimum visual signature, at night, resulting from either internal or external aircraft lighting."

3.1.4 Aural Signature

The aural signature is a primary detection source for the short-range, hand-held, and crew-served weapons. Two types of procurement requirements statements have been employed for aural signature reduction and both will be illustrated here. The first is a general requirements statement; the second provides specific quantitative requirements.

"The aural signatures shall be minimized to the most effective levels practical as determined by survivability and system cost-effectiveness analyses and trade-off studies."

The more specific requirement applies to a helicopter procurement but would also be applicable to any system which must operate close to the threat weapons.

"The contractor shall clearly define his concept of design requirements for achieving the minimum practical noise signature. External noise shall be reduced as much as possible within the constraints of performance, transportability, cost, and other relevant trade-offs. Emphasis shall be placed on the reduction of low frequency noise generated by the main and tail rotors, particularly that referred to as blade slap. Rotor rotational noises, main rotor vortex noise, gearbox noises, and turbine engine noises shall also be considered. The contractor shall describe each concept to be considered in the noise reductions.

"The contractor shall relate the noise signature level to detectability range at various altitudes and ambient noise levels. An external noise survey shall be conducted in accordance with applicable requirements.

"The desired design goal noise levels shall specify a maximum distance at which the given aircraft can be heard by the unaided ear. The ambient noise level, including meteorological data, at the listener location shall also be specified. These design goal external noise levels shall be derived from a combination of the following:

a. The band noise levels at the threshold of audibility for the maximum hearing distance (the band noise shall be increased in intensity to account for the total absorption of sound between the maximum detection distance and some convenient nearby test measurement distance.)

b. The allowable noise levels radiating into the aircraft personnel area as specified by MIL-A-8806A."

"The desired design goal noise levels are shown in the following table and shall be measured as follows: (The underlined numbers are representative values. The actual values used in the procurement should be determined through an analysis of the mission requirements.)

a. Forward flight measurements for desired design goal noise levels shall be recorded at three points along a normal to the flight path ground projection at (500) feet to either side and at the intersection. Data shall be continuously recorded on separate tape tracks for a (200)-foot altitude flight, from (5000)-feet inbound through (1000)-feet outbound.

b. The desired design goal noise levels shall be measured at (200) feet in any direction while the aircraft is at a (50)-foot hover.

Both of the above measurements shall be recorded at the design gross weight of the aircraft. Accurate tracking data shall be concurrently recorded while monitoring meteorological conditions, and just prior to the start of a flight run, a brief sample of ambient noise shall be recorded.

"The data system shall have a frequency response of (±1) db from (4) Hz to 15 Hz. Data analysis shall produce (0.5)-second interval printouts of (400) meters/second time averaged data for the duration of the test run."

DESIGN GOAL EXTERNAL NOISE LEVEL

Frequency Band	Frequency Center	Sound Pressure Level (db) (db reference = 0.0002 dyne/cm^2)
Overall		90
22.4 - 44.7	31.5	85
44.7 - 89.2	63	85
89.2 - 178	125	85
178 - 355	250	85
355 - 709	500	88
709 - 1410	1000	85
1410 - 2820	2000	81
2820 - 5630	4000	76
5630 - 11200	8000	72

(The values in the above table and the quantitative values in the preceding paragraph are representative values and should not be used without verification that they will result in the desired requirement for the procurement.)

3.1.5 Electromagnetic Radiation Detectability

"Electromagnetic radiation external to the aircraft shall be eliminated when feasible or reduced to the minimum practical level consistent with the operation and performance of the systems and subsystems of the aircraft."

3.2 SURVIVABILITY AIDS

Countermeasures can be applied to reduce the effectiveness of detection and tracking systems based on any system signatures of the aircraft. The development of the countermeasures, and counter-countermeasures equipments is based on comprehensive and highly classified threat assessments and requirements definitions and is beyond the scope of the normal S/V program procurement. There are, however, countermeasures employment and provision requirements which should be invoked upon the aircraft design as a part of the S/V program during design and development.

A typical general requirements statement is:

"The survivability of the aircraft system shall be enhanced through the use of countermeasures or counter-countermeasures as required by the system specification (or as required by survivability and system cost-effectiveness analyses)."

Another type of general requirements statement specifies the equipments to be included in the aircraft or the equipments for which provisions shall be included.

"A radar warning receiver (typical:______), a chaff dispenser (typical:______), and provisions for electronic countermeasures pads (typical:______) shall be included in the basic design of the aircraft system."

Example procurement specification paragraphs are provided in the following sections for countermeasures applicable to the individual signatures of the aircraft.

3.2.1 Radar Countermeasures

The following paragraphs may or may not be applicable to a particular system procurement They are provided as a representative "shopping list". Some of them are contradictory.

"Active electronic countermeasures shall be provided to protect the aircraft against the radar-directed weapons included in the design threat of the statement of work."

"The aircraft shall rely on passive electronic countermeasures to protect it against radar-directed threat weapons. Active electronic countermeasures shall not be provided."

"Practical and economical state-of-the-art design techniques shall be used to reduce the radar cross section of the aircraft to threat radars."

"Radar countermeasures shall not contribute to the detectability of the aircraft. Countermeasures systems, when in use, shall not interfere with or degrade the operation of other aircraft systems."

3.2.2 Infrared Countermeasures

Several typical procurement statements dealing with infrared countermeasures are provided as examples:

"The aircraft will incorporate sufficient IR countermeasures to permit operations in a _____ threat environment."

"Space, weight, and power provisions will be provided for active IR countermeasures, technology permitting, in the form of detection and decoy devices or a jammer to allow operations while maintaining any aspect angle with relation to the threat."

"Passive IR suppression will be designed into the air vehicle utilizing a combination of hot metal and exhaust plume suppression. The maximum source infrared signature levels of the aircraft, in the ___-micron bandwidth, shall not exceed ___watts per steradian (___watts per steradian desired) hot metal and___watts per steradian (___watts per steradian desired) exhaust plume CO_2. (It should be noted that these levels are dependent on the threat type, which will vary.) The total source infrared radiation signature is comprised of direct and indirect radiation from exhaust plume and hot metal parts and is measured at the emitter boundary (no atmospheric attenuation)."

3.2.3 Visual Countermeasures

The following paragraph is provided as representative of the visual countermeasures requirement:

"Use shall be made of practical, proven, and economical state-of-the-art techniques to reduce visual detectability. Examples of possible techniques are coatings, camouflage paints, and artificial illumination systems."

3.2.4 External Electromagnetic Environments

The following statement is provided as representative of the external electromagnetic environments requirement.

"The aircraft shall be designed to provide sufficient protection against external friendly and hostile electromagnetic environments to complete its mission in nonnuclear and high altitude nuclear environments."

4.0 REQUIREMENTS FOR NONNUCLEAR VULNERABILITY REDUCTION

This section presents requirements statements for the reduction of vulnerability of components of the various subsystems of the aircraft. Also included are system definitions and a listing of typical components for each system. These definitions and components lists are based on AS-4310, Aircraft Maintenance Plan Analysis (MPA) Handbook, dated 7 August 1975. The definitions and component lists are included to illustrate the number and variety of components in the various systems and the number of components that are vulnerable to the threat weapons. Also included are some components which are not usually considered in a vulnerability assessment.

Each representative paragraph or sample statement in this section is provided to serve as a guideline only, and is to be used only after appropriate tailoring or modification to meet the needs of the specific procurement specification for nonnuclear vulnerability reduction.

4.1 GENERAL REQUIREMENTS

4.1.1 Air Vehicle Design and Integration

Each procurement should contain general vulnerability reduction requirements that are applicable to all or several subsystems and to the integration of the subsystems into the air vehicle. Two such requirements statements are listed below:

"The general design configuration of the aircraft system shall be arranged to obtain the highest level of nonnuclear protection practical for the least penalties. Techniques, such as redundancy and separation, natural masking of essential components, location of fuel cells in relation to engine inlets to minimize ingestion of fuel leakage, integral armor, and isolation of hazardous elements such as armament, oxygen containers, flammable fluids, etc., from sensitive or susceptible areas shall be considered in the design."

"The predominate directions of impact for each potential hostile weapon system shall be established. The type, size, and striking velocity of hostile weapon penetrators shall be determined so that the characteristics of potential damage mechanisms may be determined. For high explosive projectiles and missile warheads, the blast impulse characteristics shall be determined so that their effect upon the aircraft system may be assessed. The aircraft design concept shall be developed using the damage producing characteristic of the hostile systems as a guide in the basic arrangement of the structure and subsystems to minimize repairs. The above data shall also be used for the detail design of structure and subsystems."

4.1.2 Minimum Performance After Damage

"As a minimum, the aircraft shall be capable of continued safe operation for at least minutes after damage from any single hit by a:

a.____-mm (API or API-T), Type____projectile impacting at a velocity of____ft/sec.
b.____-mm (HE or HEI-T), Type____projectile impacting at a velocity of____ft/sec.
c. ____-grain fragment impacting at a velocity of____ft/sec.

"The flying qualities, for safe flight after sustaining the specified hostile weapon effects, shall be no less than level 3 as defined in MIL-F-18372, MIL-F-8785B, or MIL-F-83300 (AER)."

4.1.3 Secondary Thermal Effects

"Secondary thermal effects, as a result of projectile impact, shall be minimized throughout the entire airframe. These thermal effects include burning fuel, hydraulic fluid, or oil; or "torching" from a damaged engine. The design must prevent fire and explosions in all areas of the airframe where failure to do so shall cause a forced landing."

The contribution of the oxygen system to the secondary thermal effects potential shall also be considered.

4.1.4 Reduction of Vulnerability to Ballistic Threats

"A ballistic vulnerability reduction program shall be conducted concurrent with the development program to assess effects of design changes and to provide analysis and guidance for controlling and reducing vulnerability by the most effective means. A vulnerability analysis of the complete aircraft shall be conducted and maintained. The definitions, criteria, and general methodology have been standardized by tri-service agreement."

4.1.5 Combat Damage Repairability

"In the design phase, many candidate methods are available to the contractor to produce a component or element of a subsystem to perform a given function. In the process of selecting the best combination of design features in the end product, care shall be exercised to ensure that effective battle damage repairability is incorporated. The requirements for combat damage repairability are intended as a general guide and do not limit the selections that can be made by the contractor to enhance repairability. As new materials and construction methods are developed, new repair concepts are certain to be found. An analysis shall be performed to establish the priorities for repairability features. Those items that provide the greatest benefit in terms of minimum man-house, cost, and repair downtime shall receive primary design attention so that the most effective subsystem designs may be realized. The balance of the items shall be ranked in descending order of importance.

"The design shall incorporate those features that will enhance rapid repair of battle damage, especially for forward area maintenance operations.

"Component design shall be such that removal and replacement of battle-damaged components can be accomplished by a minimal number of personnel using primarily the general mechanics tool box. Accessibility is also a prime design feature which reduces downtime."

4.1.6 Redundancy (See Section 2.2.)

4.2 FUEL SYSTEM

The fuel system is defined as those units and components which store and deliver fuel to the engine. The system includes, but is not limited to, the following types of subsystems and components:

a. Fuel Storage System
   1. Tanks.
   2. Bladders.
   3. Ventilating system.
   4. Tank interconnect system.
   5. Fill system.

b. Distribution System
   1. Plumbing.
   2. Pumps.
   3. Valves.
   4. Controls.

   5. Filters.
   6. Lines.
c. Dump System
   1. Plumbing.
   2. Valves.
   3. Controls.
d. Indicating System

The fuel tankage and distribution system represents one of the largest subsystems of the aircraft and is normally susceptible to a significant portion of the hostile weapons effects. If unprotected, the fuel system is normally the primary contributor to aircraft vulnerable area. Protection can be provided through proper design consideration. A high priority shall, therefore, be assigned to the design of the fuel system to reduce vulnerability and to permit rapid repair or replacement of battle damaged components.

The combat damage failure modes of the fuel system include the following:

a. Fuel starvation.

b. Ignition of the fuel spray in voids adjacent to fuel tanks as a result of tank penetration.

c. Fire within the tank.

d. Explosion of the fuel-air mixture in the tank ullage.

e. Fuel leakage with migration to an ignition source.

f. Tank or structural failure due to hydraulic ram damage.

The proximity of a fuel tank to the engine air inlet system can also result in another kill or damage mode due to the destruction of the engine through fuel ingestion.

Additional specification variables which could affect the vulnerability of the fuel system, and therefore must be considered, are contained in Appendix A.

Sample vulnerability reduction requirements statements for the fuel system are given in subsequent paragraphs.

4.2.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-F-38363.
b. MIL-H-7061.
c. MIL-T-27422.
d. MIL-T-5578.
e. MIL-T-25783.

f. MIL-C-83291.
g. MIL-H-18288.
h. MIL-P-46111.

4.2.2 Fuel Tank Materials and Design

The following procurement statement describes the requirements for the selection of fuel tank materials and the design of the tanks. Similar paragraphs are presented subsequently for other aspects of fuel system vulnerability.

"Consideration shall be given to the selection of materials and construction type relative to the level of damage that can be caused by the ballistic impact of a projectile in the liquid fuel sections. The amount of damage and resulting repair shall be minimized.

"For integral tanks, the construction, material, and design shall be selected to avoid shattering and large area damage that would result in extensive repair efforts or be beyond repair. For example, high strength sculptured skin with inadequate fracture toughness has shown a tendency to experience large area holes accompanied by excessive cracking due to ballistic impact.

"Integral fuel tankage shall also be designed by the use of structural design techniques which limit the damage that may occur from the hydraulic ram effects caused by the ballistic impact of a projectile in the liquid fuel sections."

4.2.3 Fuel Distribution Systems

"Fuel distribution line installations such as fuel feed, vent, and transfer lines shall be designed to be readily accessible and replaceable. Consideration shall be given to the design of interchangeable fuel line sections that will minimize the number of spare fuel lines required for replacement of damaged components.

"Fuel lines shall be shielded as much as possible and shall be routed in such a manner throughout the aircraft to minimize the complete loss of the propulsion systems due to the detonation and fragment spray of a single ______ projectile with ______ fuzing.

"Fuel lines of 1-inch diameter or greater in which fuel is moved during flight and which are located outside of fuel tanks or engine compartments/nacelles shall be of self-sealing construction or shall be protected with self-sealing covers.

"Fuel lines shall employ ballistic protection or other methods of protection such that the aircraft can complete the mission after a hit from a ____-mm API (or HEI) projectile. Protection of fuel lines and other critical fuel subsystem components against ____-mm API (or HEI) projectile shall also be considered."

4.2.4 Fuel Fire Protection

"The fuel system shall be designed to minimze loss of the aircraft from fires and explosions induced by single hits by API (or HEI) projectiles up to and including ____-mm projectiles. Compartments and spaces adjacent to and surrounding the fuel tanks will be designed to minimize loss of the aircraft due to the effects of fuel leakage and subsequent fire. A minimum of (3) inches of void filler (polyurethane foam per MIL-P-46111 or similar material) shall be applied to all voids of (3) inches or greater around tanks containing flammable fluids and to all main supply lines from those tanks or components. Equal or more effective techniques, as determined by testing, may be used if desired.

"Any compartment containing flammable fluid-carrying lines shall be vented and drained. Any such compartment containing sources of ignition will have either a fast-acting fire detection and extinguishing system, an inerting system, or other fire protection measures such as fire retardant foams, intumescent paints, external void-filler foams, or other techniques as approved by the procuring agency. Inerting and fire detection and extinguishing systems, if used anywhere in the aircraft, shall either be redundant, shielded, or installed in such a manner that the system will continue to provide protection against fires and explosions if hit by a single API (or HEI) projectile up to and including ______ projectiles."

4.2.5 Fuel Management

"The fuel subsystem shall provide a two-way fuel transfer between all internal fuel cells to provide the capability to transfer fuel from any one cell or tank to another and to provide for crossfeed capability. Fuel tank selection switches and appropriate fuel system equipment shall be provided to allow the pilot to either prevent the in-flight refueling of battle-damaged fuel tanks or to prevent other fuel tanks from feeding a battle-damaged fuel tank.

"*All single-point failure sites in the fuel system, especially crossfeed points, shall either* be eliminated, shielded, or protected by armor to minimize the complete loss of the fuel system due to single hits by API (or HEI) projectiles up to and including ______ and ______ projectiles."

4.2.6 Fuel Reserve

"A ____-minute or ____-nautical mile fuel reserve for flight at maximum range airspeed (without external ordnance) at the design gross weight shall be protected or self-sealed against ______ projectiles."

4.2.7 Electromagnetic Pulse and Lightning Protection

"All components of the fuel system shall be protected against the effects of electromagnetic pulses and lightning. Specifically, the fuel quantity measurement system shall be designed to prevent arcing in the fuel tanks. This protection shall be of sufficient magnitude to prevent ignition of the fuel vapors."

4.3 FLIGHT CONTROL SYSTEM

The flight control system consists of those units and components which furnish a means of manually controlling the flight attitude characteristics of the aircraft. The system includes, but is not limited to, the following types of subsystems and components:

a. Control column linkage.
b. Rudder pedals.
c. Control cables.
d. Tab controls.
e. Hydraulic or electrical boost systems.
f. Control surfaces.
g. Actuators.
h. Bell cranks.
i. Push-pull rods.
j. Pulleys.
k. Attach fittings.
l. Hinges.
m. Position indicators.
n. Jackscrews.
o. Motors.
p. Control handles.
q. Electronic computers/mixers.
r. Mechanical mixers/ratio changers.
s. Electrical circuits.

The flight control system is vulnerable, primarily to the penetration weapon effect with the principal damage modes being the cutting, deforming, binding, or jamming of the components of the system. Actuators are also vulnerable to the hydraulic ram damage mode and nearly all of the components are vulnerable to burn-through or melting from secondary flame or hot gas effects.

Additional specification variables which could affect the vulnerability of the flight control system, and therefore must be considered, are contained in Appendix A.

Since the primary damage mode is the result of either a projectile or fragment impact, the most frequently used protection concepts are to provide redundancy and to harden ballistically. Sample vulnerability reduction requirements statements for the flight control system are presented in the subsequent paragraphs.

4.3.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-F-18372.
b. MIL-F-9490.
c. MIL-F-83300.
d. MIL-F-8785.
e. MIL-H-8501.

4.3.2 Primary Flight Control System

"The primary flight control system shall be designed to preclude loss of flight path control due to single hits by API projectiles up to and including ___-mm (API or API-T). Type ______ projectiles. To accomplish this, techniques such as dual, completely independent, and widely separated control paths and dual, completely independent, and widely separated control paths and dual, completely independent, and widely separated hydraulic systems shall be used."

"Singly vulnerable points within the flight control system shall be minimized. No failure may be accompanied by a hard-over signal to a control surface actuator."

"All single-point failure sites in the flight control systems, such as redundant components in close proximity to each other and nonredundant safety of flight critical components, shall be protected by armor to prevent loss of flight control when hit from any direction by single API projectiles up to and including ___-mm (API or API-T), Type ______ and single ___-mm (HEI or HEI-T) projectiles.

"From all aspect angles, except the top view, the control stick and its nonredundant linkages in the armored cockpit area shall be protected against single hits by API projectiles up to and including ___-mm (API or API-T), Type ______ and by ___-mm (HEI or HEI-T) projectiles.

Armor used to protect any portion of the flight control system will:

a. Not cause jamming of the control system due to spallation, fragmentation, or break-up of the armor when hit by single API projectiles up to and including ___-mm (API or API-T), Type ______ and by ___-mm (HEI or HEI-T) projectiles.

b. Comply with the system separation and vulnerability requirements for the flight control system as specified in paragraphs 3.2.5.1 and 3.2.5.2 of MIL-F-9490C."

4.3.3 Manual Reversion Flight Control System

"The manual reversion flight control system shall serve as a back up system to preclude loss of flight path control due to multiple hits by API projectiles up to and including ___-mm (API or API-T), Type ______ and by ___-mm (HEI or HEI-T) projectiles which cause complete loss of power in all hydraulic systems. The manual reversion flight control system and primary flight control system shall be separated as much as possible or routed/shielded in such a manner as to prevent loss of flight path control due to the detonation and fragment spray of a single ___-mm (HEI or HEI-T), Type ______ projectile with ______ fuzing."

4.3.4 Flight Control Subsystems and Components

"The flight control subsystems and components consist of controls for the pilot (and copilot), mechanical, electrical, or hydraulic linkages to the control surfaces (and rotors), and augmentation equipment if required. Transfer of inputs from the cockpit to the control surfaces may be by mechanical or electrical means. Vulnerability reduction requirements for these subsystems are as follows:

4.3.4.1 Mechanical Linkages. "If the standard mechanical subsystem of linkages is used to actuate the primary flight control surfaces, such components as cables, pulleys, push-pull rods, torque tubes, levers, bell cracks, and associated brackets should be considered critical to vulnerability. Survivability design techniques for the critical mechanical flight control components shall include but are not limited to, the following:

4.3.4.1.1 "Duplicate flight control mechanical linkages should be provided to permit full flight control surface motion through one redundant path in the event the other path is severed or jammed by projectile damage. Jam protection or jam override should be included in the design.

4.3.4.1.2 "Routing of duplicate cables, push-pull rods, and other components shall be sufficiently separated to preclude damage to both by the same projectile.

4.3.4.1.3 "Heavy structure should be used to shield control cables and push-pull rods. These linkage elements shall be routed closely to primary structure or in areas of the airframe least likely to sustain enemy gunfire damage. Care shall be taken to avoid passage of rod and cables through narrow spaces between two near-parallel planes of skin or skin structures where buckling of either adjacent surface against the other by bullet impact or blast could pinch or jam the control element.

4.3.4.1.4 "Self-aligning bearings shall be used for all torque tube installations to prevent or minimize the possibility of jamming from deformation of the torque tube or supporting structures after projectile impact.

4.3.4.1.5 "Heat resistant materials shall be used to protect mechanical control elements where fires or hot gas impingement could develop as secondary damage from weapon effects.

4.3.4.1.6 "The use of brittle materials, such as castings which would shatter or otherwise fail when struck by a projectile, should be avoided in the design of mechanical elements. Ductile materials, such as sheet or plate weldments, polyamide, or other non-metallics (possible in laminated form), or composite honeycomb constructions which will accept penetration with minimum local damage at the impact point and without propagating into critical or total damage to the mechanical function, should be used in the design of these elements."

4.3.4.2 Flight Control Power or Boost Systems. "The design shall include jam resistant and jam override protection where required to assure that no single failure, projectile damage, or malfunction in any part or component may cause failure of both flight control power or boost subsystems.

4.3.4.2.1 "Where additional power is required to actuate or position essential flight controls, all assist components and power sources should be duplicated, well separated, and independent to include reserve power storage provisions for emergency landing after total loss of power. Reserve power storage provisions shall ensure a minimum control usage landing with one 180° heading change and, for helicopters, four collective strokes.

4.3.4.2.2 "Flight-critical functions in the primary control subsystems should be powered or boosted independently from utility and other functions not critical to safe flight.

4.3.4.3 Actuators. "All actuators employed in the flight control system shall be of the antijam type.

4.3.4.4 Control Surfaces. "The control surface design, construction, and the hinges at each control surface shall be of such number, placement, or hardness that single hits by API projectiles up to and including __-mm (API or API-T), Type______ and by___-mm (HEI or HEI-T) projectiles will not cause the affected surface to:

a. Inflict damage on other portions of the aircraft due to complete or partial separation from the vehicle.

b. Create unsafe flutter conditions due to the effects of mass unbalance, partial loss of effective area, partial separation from the vehicle, or other predictable effects.

4.3.4.4.1 "Multiple control surfaces shall be used, where practicable, to maintain the required flight path control and handling qualities in a hostile threat environment.

4.3.4.4.2 "Destruction of jamming of any one pitch or roll control surface/control actuator/hinge point shall not prevent usable actuation (sufficient for flight and landing) of the remaining pitch or roll control surfaces."

4.3.4.5 Additional Considerations. "The design of the flight control system must incorporate the following additional considerations:

4.3.4.5.1 "Fault detection and switching equipment shall be incorporated. Notice of failures of all pilot-assist functions shall be given to the pilot or copilot. Failures of augmentation functions shall result in that function being switched off. Redundancy of flight control subsystem components shall be such that components that are essential to flight have a separated backup subsystem. The aircraft shall be controllable and remain mission safe in all normal flight modes should failure of a primary power assist subsystem occur. If a second control system failure should occur after a primary assist subsystem failure, the aircraft shall remain fail-safe thereby allowing it to be maneuvered to a safe landing.

4.3.4.5.2 "All components in the flight control system must be fail-safe. That is, in the event of loss of control to any of the control surfaces, the surface will fail to a position to maintain level flight. No failure may be accompanied by a hard-over signal.

4.3.4.5.3 "Disconnect or other means of removal should be provided for extensions of any subsystem not to be used in the combat zone if connected to flight-critical functions."

4.3.5 Battle Damage Repairability

"The components in flight control systems shall be designed to permit the removal and replacement of a damaged item with a minimum of disassembly of the overall system. Particular attention shall be paid to development of the system so that rigging or adjustments may be accomplished in sections so that a minimum of readjustments or rerigging will be required for battle damage repair."

4.3.5.1 "Support brackets for the mechanical systems shall be designed to be damage tolerant and be repairable for a reasonable degree of battle damage. Easily shattered materials should be avoided for supports.

4.3.5.2 "The mechanical linkages of a flight control system of an aircraft shall be designed in a manner to permit rapid access for inspection and repair of battle damage.

4.3.5.3 "Major flight control surfaces shall be made removable for repair or replacement without dismantling primary structural elements.

4.3.5.4 "Electronic portions of the control system shall be designed for replacement of damaged components with a minimum of recalibration or readjustment to match other components in the system.

4.3.5.5 "Avionic components in flight control systems are usually complex, expensive to replace, and normally beyond the repair capability of the operational unit. Components in this category shall receive priority in locations that would minimize their probability of being damaged. Those that are required for mission accomplishment shall be ranked ahead of those that are in the pilot-assist category."

4.4 FLUID POWER SYSTEM

The fluid power system consists of those units and components which provide hydraulic fluid under pressure or compressed air as a power source and is normally further broken down into hydraulic systems and pneumatic systems. The hydraulic system includes, but is not limited to, the following types of components:

a. Tanks.
b. Accumulators.
c. Pumps.
d. Valves.
e. Levers.
f. Switches.
g. Plumbing (lines, connectors, etc.)
h. Indicating system.

The pneumatic system includes, but is not limited to, the following types of components:

a. Ducts and lines.
b. Valves.
c. Actuators.
d. Heat exchangers.
e. Controls.
f. Temperature and pressure indicators.

The fluid power systems, because they are pressurized, are extremely vulnerable to the penetration weapon effects of projectile and fragment kill mechanisms as well as penetration by secondary kill mechanisms of spall and burn-through. Hydraulic systems, depending upon the type of fluid employed, are also vulnerable as a source of combustibles for fire. Severing of the components of the systems can also be caused by airframe displacement or distortions which result from either internal or external projectile detonations.

Additional specification variables which could affect the vulnerability of the fluid power system, and therefore must be considered, are contained in Appendix A. The specification of these variables must also include both the functional kill of the systems and loss of fluid power, as well as ignition of the hydraulic fluid in the case of the hydraulic system.

Sample vulnerability reduction requirements statements for the fluid power system are given in subsequent paragraphs.

4.4.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-H-5440.
b. MIL-H-8891.
c. MIL-P-5518.
d. MIL-H-8775.
e. MIL-H-8890.
f. MIL-P-8564.
g. MIL-H-83282.

4.4.2 Fluid Power or Boost

"Where a fluid power subsystem is utilized to power or boost flight control forces, survivability design features or techniques shall include, but are not limited to, the following considerations:

a. Where additional power is required to actuate or position essential flight controls, all assist components should be duplicated (redundant) and well separated.

b. The subsystem should be designed not to jam or allow an uncorrectable extreme control configuration to occur after projectile damage.

c. A separate power source for each redundant unit should be provided.

d. Reserve power storage provisions should be incorporated into the design. These provisions shall allow reasonably unhampered control operations during an emergency landing following loss of power.

e. Flight-critical control functions should be powered or boosted independently from utility and other control functions not critical to safe flight.

f. Disconnect or other means or removal should be provided for extensions of any subsystem not to be used in the combat zone if connected to flight-critical functions."

4.4.2.1 "Two or more independent hydraulic actuating subsystems shall be used. A failure in one subsystem shall not adversely affect the functioning of the other subsystem or subsystems. Redundance or use of backup flight control subsystems requires that each be fully independent of the other and that each system be capable of performing all essential subsystem control functions when the other subsystem is incapacitated. This will require two or more hydraulic pumps. Also, a single failure in any other aircraft subsystem shall not incapacitate two or more independent hydraulic control subsystems simultaneously.

4.4.2.2 "The fluid power systems shall incorporate design features to preclude loss of more than one system due to single hits from:

a. ____-mm (API or API-T), Type______projectile impacting at a velocity of____ft sec.

b. ____-mm (HEI or HEI-T), Type______ projectile impacting at a velocity of____ft/sec.

c. A ____-grain fragment impacting at a velocity of____ft/sec.

4.4.2.3 "Routing and separation of the fluid control systems shall be such that:

a. Maximum protection is afforded by masking or shielding.

b. Split-body or rip-stop design shall be used in dual tandem actuator designs.

4.4.2.4 "The following component considerations will be incorporated:

4.4.2.4.1 "Pressurized vessels, such as hydraulic or pneumatic accumulators, shall be designed to be nonshatterable when struck by ballistic threats. This is to minimize the probability of creating secondary damage fragments that would cause additional repair efforts.

4.4.2.4.2 "Consideration shall also be made for the incorporation of high temperature blow-out plugs in the high pressure gas sections of such vessels that may be exposed to fires or hot gases created by hostile weapon effects.

4.4.2.4.3 "Where hydraulic lines are installed in areas of potential high temperature hazards, due to hostile weapon effects, consideration of thermal protection techniques shall be made.

4.4.2.4.4 "Low flammability hydraulic fluid (such as MIL-H-83282) shall be used in the production aircraft."

4.4.3 Battle Damage Repairability

"The distribution lines or hoses shall be designed to achieve ease of access, inspection, removal, and replacement of damaged lines/hoses. Special evaluation shall be made of the line connector features to ensure that minimum disassembly of other components is required to disconnect and reconnect the lines/hoses. Where brazed or welded line connections are contemplated, consideration for operational unit skill, equipment, and available facilities shall be made. Provisions shall be considered in hydraulic systems to prevent the total loss of a system through use of circuit failure detection and isolation techniques to minimize possible damage to the hydraulic pumps from cavitation. Such provisions also may be employed to limit the amount of hydraulic fluid liberated by battle damage and thereby minimize potential fires and other secondary damage. Components such as pumps, valves, filter assemblies, etc., in hydraulic or pneumatic systems should be as interchangeable as possible so that the spare parts required for repair may be minimized and effective cannibalization from one aircraft to another permitted."

4.5 ENGINE AND ACCESSORY DRIVE SYSTEM

For the purposes of this document, this system is defined to include the engine, the basic engine accessories, and engine controls, engine indicating system, oil system, exhaust system, air system, engine fuel and fuel control system, and the accessory drive system.

The engine itself consists of several major subsections or functional subsystems. These are:

a. The air inlet section. This is the section of the engine through which the air enters at the compressor section and is composed of:

   1. Guide vanes.
   2. Shrouds.
   3. Cases.

b. The compressor section which consists of:

   1. Cases.
   2. Vanes.
   3. Shrouds.
   4. Rotors.
   5. Diffusers.
   6. Shafts.

c. The combustion section, in which the air and fuel are combined and burned, consist of:

   1. Burner.
   2. Case.
   3. Nozzles.

d. The turbine section which includes:

   1. Case.
   2. Rotors.
   3. Blades.
   4. Shaft.

e. The bypass section which bypasses a portion of the normal engine airflow (either ram or compressed air) for the purpose of adding to engine thrust or reducing fuel consumption. This section includes:

1. Ducting or shrouds.
2. Vanes.
3. Controls.

f. The augmentation section which is utilized for the recovery of or addition of power to the engine system. This section includes:

1. Case.
2. Nozzles.

g. The engine controls which link the control inputs to the engine:

1. Linkages.
2. Levers.
3. Cables.
4. Pulleys.
5. Switches.
6. Wiring.

h. The engine indicating system including:

1. Indicators.
2. Transmitters.
3. Analyzers.
4. Phase detectors.
5. Generators.
6. Wiring.
7. Amplifiers.
8. Oscilloscopes.
9. Monitoring system.
10. Recording system.

i. The ignition system which consists of those units and components which generate, control, furnish, or distribute an electrical current to ignite the fuel-air mixture in the cylinders of reciprocating engines or in the combustion chambers or thrust augmenters or turbine engines. The components of these systems are:

1. Induction vibrators.
2. Magnetos.
3. Switches.
4. Lead filters.
5. Distributors.
6. Harnesses.
7. Plugs.
8. Ignition relays.
9. Exciters.
10. Storage capacitors.
11. Compositors.
12. High tension leads.

13. Coils.
14. Igniters.
15. Ignition switches.
16. Wiring.
17. Connectors.

j. The oil system which consists of those units and components external to the engine which store lubricating oil and deliver it to and from the engine as well as those used to distribute oil throughout the engine. The oil system components are:

1. Tanks.
2. Heat exchangers.
3. Pumps.
4. Strainers.
5. Valves.
6. Scavenger pumps.
7. Sumps.
8. Indicators.
9. Wiring.
10. Transmitters.
11. Deoilers.
12. Deaerators.
13. Filters.
14. Plumbing.

k. The engine exhaust system which is composed of those units and components which direct or vector the engine exhaust gases overboard. These components are:

1. Collector rings.
2. Exhaust and thrust augmentor ducts.
3. Variable nozzles.
4. Actuators.
5. Plumbing linkages.
6. Wiring.
7. Position indicators.
8. Warning systems.
9. Noise suppressors.
10. Clamshells.
11. Thrust reverser linkages and controls.
12. Tertiary air doors and controls.

l. The air system of turbine engines which includes those external units and components and integral basic engine parts which go together to conduct air to various portions of the engine and to the extension shaft and torquemeter assembly, if applicable. The components are:

1. Compressor bleed section.
2. Cooling air system.
3. Engine anti-icing hot air systems.
4. Valves.

5. Plumbing.
6. Wiring.
7. Regulators.
8. Governors.
9. Actuators.
10. Linkages.
11. Transmitters.
12. Indicators.

m. The engine fuel and fuel control system. For turbine engines, this system includes those units and components and associated mechanical systems or electrical circuits which furnish or control fuel to the engine and thrust augmenter which are located beyond the engine main fuel quick disconnect. The system also includes the fuel flow rate sensing, transmitting, or indicating units whether the units are located before or beyond the quick disconnect. The components of the system are:

1. Coordinator or equivalent component.
2. Engine driven fuel pumps.
3. Filter assembles.
4. Main fuel controls.
5. Thrust augmentor fuel controls.
6. Electronic temperature datum controls.
7. Temperature datum valve.
8. Fuel manifold.
9. Fuel nozzles.
10. Fuel enrichment system.
11. Speed sensitive switches.
12. Relay box assemblies.
13. Solenoid drip valves.
14. Burner drain valves.
15. Temperature regulators.
16. Valves.
17. Levers.
18. Cables.
19. Pulleys.
20. Linkage.
21. Indicating systems.
22. Wiring.

n. Accessory drive system which is defined to include those units and components, either engine-mounted or remotely installed and connected to the engine by a drive shaft, which drive multiple types of accessories. The components of the accessory drive system include:

1. Drive shaft.
2. Adapters.
3. Seals.
4. Mechanical generator drives.
5. Gears.

6. Oil pumps.
7. Coolers.
8. Cases.

Engine vulnerability is complex with the lethal damage modes varying among the subsystems and components but nearly all of the elements of the system are vulnerable to the penetration weapon effect. The components that have an interface with the liquid fuel or oil also are vulnerable to the incendiary and hydraulic ram weapon effects associated with penetrating projectiles or fragments.

Projectile blast pressures, in either the air inlet section or the exhaust section, may affect the performance of the engine. The engine is also highly vulnerable to fuel ingestion caused by fuel system damage adjacent to the air inlet section.

The engine, when damaged, can also create secondary kill mechanisms which are at times more lethal to the aircraft than were the primary kill mechanisms. These secondary kill mechanisms include fire, hot gas torching or emission, and the generation of projectiles due to the breaking of elements on the high speed rotating components of the engine (compressor and turbine blades).

Additional specification variables which could affect the vulnerability of the engine and accessory drive system, and therefore must be considered, are contained in Appendix A.

Sample vulnerability reduction requirements statements for the engine and accessory drive system are given in subsequent paragraphs.

4.5.1 Applicable References

Applicable references for the survivability and design of the engine and accessory drive system are as follows:

a. MIL-L-23699.
b. MIL-L-7808.
c. MIL-G-83363.
d. MIL-T-5955.
e. MIL-T-5579.
f. MIL-E-5007.
g. MIL-E-8593.

4.5.2 Engine System

"The engine system shall be configured to minimize the probability of complete power failure due to a single hit from a _____ projectile impacting at ____ ft/sec or the specified fragment impacting at ____ ft/sec. The protection of critical engine components and accessories shall be provided in the aircraft design against the specified fragment by using shielding offered by structural members, other equipment, and armor as required. The engine mounting system shall be such as to preclude failure from a single hit by the _____ threat. Engine fan blade containment measures shall be incorporated. The airframe design shall assure the compatibility of the airframe/engine accessory/complete power transmission subsystem structural and dynamic interrelationships.

"The engines shall be isolated from fuel tanks as much as possible and protection measures shall be taken to isolate engine fires and to prevent them from spreading beyond the engine compartmental nacelles.

"The engine compartments/nacelles shall be drained and means shall be provided for shutting off the flow of flammable fluids into and through the engine compartments/nacelles.

"A highly reliable and survivable fire detection system plus fast-acting, multiple-shot fire extinguishers shall be installed in each engine compartment/nacelle."

4.5.3.1 Multiple-Engine Aircraft. "For multiple-engine aircraft, the engines shall be physically separated or protected, including thermal insulation if required, to prevent complete power failure due to a hit from a single______projectile or the specified fragment. Design techniques shall be used to prevent or minimize the probability of combat damage response of one engine propagating to another engine and causing failure or degrading performance.

"The engines shall be completely independent with separate fuel and oil tankage, feed lines, pumps, and controls."

4.5.3 Gearboxes/Transmissions

"Transmissions and gearboxes shall function satisfactorily throughout their complete operating envelope when using oil conforming to and having any of the variations in characteristics permitted by MIL-L-23699, MIL-L-7808, or MIL-G-83363. Capability for using a common lubricant in engines, transmissions, and gearboxes is desired. Lubricant shall not be completely depleted in the event of a rotating shaft seal failure. No external leakage from the main transmission onto the aircraft structure shall be permitted. The status seals shall not permit leakage. Rotating shaft seals shall be selected for maximum reliability, and in those cases where a small amount of oil seepage is possible, provisions shall be made for collection to overboard drains. The subsystem shall be in accordance with MIL-T-5955 and shall comply with the following:

a. Oil sumps and external tank and lines shall be self-sealing against______API projectiles or shielded or armored to defeat a_____API or HEI projectile. Self-sealing shall be in accordance with MIL-T-5579, Type II.

b. The gearboxes/transmissions components shall be designed to operate at sea level standard conditions for no less than 30 minutes after total loss of the lubrication system.

c. The oil filtration subsystem shall have an automatic emergency bypass.

d. Oil coolers shall have an automatic bypass valve to accommodate cold starts and ballistic hits in the oil cooler."

4.6 POWERPLANT INSTALLATION

The powerplant installation system includes those units and components required to mount and house the engine and accessory drive system and to provide the physical interfaces with the aircraft structure and the aerodynamic surfaces of the aircraft. The following are included in the powerplant installation system:

a. Cowling – those removable coverings which extend over and around the powerplant assembly. It includes:

   1. Cowl flaps.
   2. Supports.
   3. Attach and locking mechanisms.

b. Mounts – the framework, either of built-up construction or forgings, which supports the engine and attaches it to the nacelle or pylon.

   1. Engine mounts.
   2. Vibration dampers.
   3. Support links.
   4. Mounting bolts.

c. Fireseals – those fire-resistant partitions and seals mounted on or about the power package for the purpose of isolating areas subject to fire.

   1. Firewalls.
   2. Flame resistant/tolerant fillers.
   3. Intumescent coatings.

d. Attach fittings – those fittings and brackets which are used for the support of equipment in and about the power package.

e. Electrical harness – those electrical power supply components which serve several powerplant systems but which are banded together to facilitate the installation and removal of the powerplant including:

   1. Cables.
   2. Conduits.
   3. Plugs.
   4. Sockets.

f. Air intakes – that portion of the powerplant system which directs and may or may not vary the mass airflow of the engine. Included are:

   1. Nose ring cowls.
   2. Scoops.
   3. Compressor fan cowls.
   4. Buried engine ducts.
   5. Vortex generators.

6. Actuators.
7. Control handles.
8. Cables.
9. Wiring.
10. Plumbing.
11. Linkage.
12. Doors.
13. Indicating systems.

g. Engine drains – those component and manifold assemblies which are used to drain off excess fluid from the powerplant and its accessories. They include:

1. Drain lines.
2. Manifold.
3. Tanks.
4. Flame arresters.
5. Vents.
6. Supporting brackets.

The powerplant installation system components are primarily physical interface components and are vulnerable to penetration, blast, and burn-through weapon effects. The key variables which are required in the survivability specification are, as with the engine and accessory drive system, those that define the threat and the number of hits the system must be capable of taking without a kill.

Additional specification variables which could affect the vulnerability of the power installation system, and therefore must be considered, are contained in Appendix A.

The powerplant installation system protection techniques to be considered in the design shall include the following:

a. "The powerplant mount system shall preclude an attrition kill from a single hit by the ___-mm API or the ______ HEI threat.

b. "Mission kits should be considered as armor installations for the protection of singly vulnerable components.

c. "Ballistic protection shall be considered for the oil tank, oil cooler, oil lines, and engine fuel lines."

Additional sample vulnerability reduction requirements statements are given in subsequent paragraphs.

4.6.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-C-22284.
b. MIL-C-22285.
c. MIL-I-83294.
d. MIL-D-27729.
e. MIL-F-23447.
f. MIL-F-7872.

4.6.2 Fire Protection

"Fire is the predominate secondary weapon effect experienced in combat. It can be fed by either leaking fuel, lubrication, or hydraulic oil. Therefore, provisions shall be considered to limit the amount of fire damage that can be propagated to other portions of the aircraft so that survivable damage may be repaired for the least expenditure of time and effort.

"Since the probability of fire as a result of hostile weapon effects exists for powerplant installations, consideration shall be given to the incorporation of fire detection and extinguishing systems. Heat barriers shall also be considered in areas where a high probability of fire (given a hit by weapon effects) exists. Where fire damage can occur, provisions shall be made to permit removal and replacement of the installation structure as an interchangeable unit on all aircraft of the same model."

4.6.3 Battle Damage Repair

"Aircraft powerplant installation systems shall be designed to limit the amount of damage that may be sustained from the direct and secondary effects of hostile weapons. Repair of battle damaged powerplant installations in aircraft have constituted a significant portion of the total aircraft system repair activities. Therefore, the powerplant installations shall be designed so that rapid access, inspection, removal, and replacement of engines may be accomplished. Design criteria shall also be established for the modular construction of major sections of the powerplant to permit cannibalization of other damaged powerplants so that an operational powerplant can be assembled."

4.7 PROPELLER SYSTEM

The propeller system includes those units and components that comprise the mechanically or electrically controlled propeller. The following types of components are included in the propeller system.

a. Blades.
b. Dome.
c. Hub.
d. Spinner.
e. Slip rings.
f. Deicer boot.
g. Synchronizers.
h. Distributor valve.
i. Indicating system.
j. Governor.

k. Braking mechanisms.
l. Plumbing.
m. Shafts.
n. Reduction gears.
o. Torque meters.

The propeller system is primarily vulnerable to the impact/penetration weapon effect. Components are damaged or failed through deformation, perforation, or severing.

Additional specification variables which could affect the vulnerablility of the propeller system, and therefore must be considered, are contained in Appendix A.

4.7.1 Applicable References

MIL-P-26366 is a reference for the survivability and design of the subsystem. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

4.7.2 Propeller System Vulnerability Reduction

A sample requirements statement for vulnerability reduction of the propeller system is as follows.

"The propeller system shall be designed to minimize the probability of failure due to a single hit by a ___-mm API projectile or ___-mm HEI projectile. Failure modes to be considered shall include imbalance, loss of propeller pitch control, overspeed, and loss of lubrication."

4.8 ROTOR AND POWERTRAIN SYSTEM

This system includes all those units and components which comprise the main rotor system and the antitorque rotor system. Included in the system are the following types of components:

a. Rotor blades

   1. Spars.
   2. Skin.

b. Rotor heads

   1. Plates.
   2. Swash plates.
   3. Hinge pins.
   4. Fold assemblies.
   5. Pitch horn.
   6. Pitch change rods, links.
   7. Stationary scissors.

8. Rotating scissors.
9. Pitch beam assembly.
10. Sleeve and bearing.
11. Extension shaft.
12. Governors.
13. Synchronizers.
14. Switches.
15. Levers.
16. Rods.
17. Cables.
18. Hubs.
19. Brake mechanisms.
20. Rotating portion of the ice and rain protection system.

c. Powertrain

1. Transmissions.
2. Gearboxes.
3. Driveshafts.
4. Couplings.
5. Oil systems.

d. Fairings.

The components of the rotor system are vulnerable to the penetration (performation or severing) weapon effect of projectiles and fragments; the rotor blades are also vulnerable to the blast weapon effects of projectiles or missiles and combined blast and fragmentation kill mechanisms.

The most important parameters to be defined in the rotor system survivability specification are those that define the threat weapon and its kill mechanisms and the energy levels (mass and velocity) of these kill mechanisms.

The transmission and gearbox components of the powertrain, and the many bearing surfaces are also vulnerable to loss of lubricant. In addition to the threat definition, the survivability specification should also specify the length of time the bearings must retain their functional capability after a damaging hit that would degrade or destroy the normal lubrication capability.

Additional specification variables which could affect the vulnerability of the rotor and powertrain system, and therefore must be considered, are contained in Appendix A.

Sample vulnerability reduction requirements statements for the rotor and powertrain system are given in subsequent paragraphs

4.8.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003. Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-L-23699.
b. MIL-S-8698.
c. MIL-T-5579.
d. MIL-T-5955.
e. MIL-L-7808.

4.8.2 Powertrain Systems

"The powertrain system shall consist of all components and subsystems required to transmit power from the engine(s) to the rotors and accessory inputs. The system includes engine input shafting, clutches, reduction units, main rotor gearbox, accessory gearbox drive and pads, output shafting, rotor brake, and associated cooling and lubrication subsystems.

4.8.2.1 "The powertrain subsystem components shall be designed to operate at sea level standard conditions for no less than (30 minutes) after total loss of the lubrication subsystem.

4.8.2.1.1 "The powertrain subsystem components including, but not limited to, shafts, couplings, bearings, and gears shall be designed to prevent total failure for a minimum of (30 minutes) at maximum operating loads when impacted by a ______ projectile.

4.8.2.1.2 "Powertrain subsystems, such as those employed by rotary wing aircraft, shall be designed to be as damage tolerant as practical against a ______ projectile. Redundant or armor-protected elements shall be considered as methods to obtain the specified or established protection levels. Delayed failure from loss of lubrication shall be utilized for essential powertrain elements where effective. Lower speed rotating shafts should be considered to minimize subsystem failure from damaged hanger bearing assemblies.

4.8.2.1.3 "Powertrain cooling and lubrication systems shall be designed so that:

a. The oil sumps, external tanks, and lines shall be self-sealing against the ______ projectile.

b. Automatic bypass valves installed within the oil coolers shall accommodate cold starts and ballistic hits in the oil cooler.

c. The oil filtration subsystem shall have an automatic emergency bypass.

4.8.2.1.4 "Lubrication lines and tanks shall be self-sealing against ______ projectiles or shielded or armored to defeat a ______ projectile.

4.8.2.1.5 "During autorotation and single engine operation, the engine(s) not supplying torque shall be immediately and automatically decoupled from the drive subsystem by overrunning clutches to permit continued operation of the main rotor, tail rotor, and accessory drive. The overrunning clutch shall be designed so that its limit torque capacity is the limit input torque increased by a factor of (2.0). The bearings and lubrication subsystem and the clutch shall be such that the (2-hour) period of full overrunning is permissible without any impairment and complete loss of the transmission lubrication subsystem shall not prevent full overrunning for (30 minutes).

4.8.2.1.6 "The accessory gearbox shall be driven by the main gearbox. Flight critical accessories shall also be driven by the main rotor shaft independently of the engines during autorotation."

4.8.3 Drive Subsystem

The following vulnerability reduction requirements are presented for drive subsystem components.

4.8.3.1 "The drive subsystem shall be designed for the lowest practical vulnerability to enemy weapons. The number of drive subsystem components shall be kept to a minimum and drive shafts shall be as short as possible. Nonredundant vulnerable components shall have design features which prevent total failure when impacted by______projectiles.

4.8.3.2 "When the basic design cannot provide adequate survivability to critical parts (e.g., bearings and gears), they shall be protected by incorporating armor liners around the part or shall be provided protection through the use of armor plate, preferably integrated into the design.

4.8.3.3 "Materials to be considered for reducing the vulnerability of drive shafts include but are not limited to fiber composite plastics (such as glass, carbon, and boron) as well as various metal or metal matrix configurations.

4.8.3.4 "Construction of component cases, housings, and sumps shall utilize materials and designs that minimize damage from projectile impact and also incorporate a self-sealing capability where loss of lubricating or cooling oil is cirtical. Lubrication lines and external components shall be eliminated to the maximum extent possible. Each gearbox or transmission shall contain its own integral lubrication, cooling, and reservoir subsystem.

4.8.3.5 "Installation of high speed parts (e.g., drive shaft) close to very critical or vital components shall be avoided to prevent serious secondary damage.

4.8.3.6 "Survivability design features which should be considered include, but are not limited to, high temperature bearing materials, self lubricating or sintered metal bearing retainers, bearing clearance tolerance to temperature higher than normal operating temperatures, improved heat transfer paths away from bearings, and auxiliary or backup lubrication provisions to service critical areas in emergency. Considerations should be given to the use of bearings with solid lubricant retainers and gears using solid lubricant idlers which perform satisfactorily during normal operation with oil lubrication and which provide a (30-minute) operation life after complete oil loss."

4.8.4 Rotor System

"The rotor system shall be designed to allow safe flight after a hit by a ___-mm projectile."

4.9 STRUCTURAL SYSTEM

The structural system consists of all of the components or members employed to establish the configuration of the aircraft and to transmit and react all gravitational and aerodynamic loads. The structure consists of the following component types which have been grouped into fuselage, wing, and empennage subsystems:

a. Fuselage

1. Frames.
2. Longerons.
3. Bulkheads.
4. Formers.
5. Stringers.
6. Skin.
7. Attach fittings.
8. Aerodynamic fairings.
9. Internal stores mounts.
10. Canopy, windows, windshield.

b. Wing

1. Spars.
2. Ribs.
3. Stringers.
4. Skins.
5. Control surface structure.
6. Folding mechanisms.
7. External store mounts.
8. Attach fittings.

c. Empennage [horizontal stabilizer(s), vertical stabilizer(s), rudders, elevators/elevons]:

1. Spars.
2. Ribs.
3. Stringers.
4. Skin.
5. Attach fittings.

The vulnerability of the canopy, windows, and windshields is closely associated with the vulnerability of the crew and passengers and is discussed in Section 4.16.

The structure is vulnerable to any kill mechanisms which reduce the load-carrying strength of the structural components, result in a change or misalignment of loadpaths, or increase (including transient impulses) the load on the structure. The primary kill mechanisms which can cause these damage modes are projectiles, fragments, thermal energy, and blast. The structure is also vulnerable to the secondary kill mechanism of fire and may be vulnerable to spall depending upon the size and composition of the structural members and of the spall missiles.

The variables which must be addressed in the structural survivability specification include those that describe the threat and its kill mechanisms (mass, velocity, temperature, thermal and blast energies, etc.) and the kill criteria for the structure. The kill criteria may include the definition of the required residual strength capability, after the damage by the threat kill mechanisms, or the required mission performance capabilities that must remain after the structure is damaged.

Additional specification variables which could affect the vulnerability of the structural system, and therefore must be considered, are contained in Appendix A.

Sample vulnerability reduction requirements statements for the structural system are given in subsequent paragraphs.

4.9.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-A-8860.

b. MIL-S-8698.

c. MIL-STD-850.

d. T.O. 1F-111A-3-1, Technical Manual Structural Repair Instructions, Combat/Battle Damage, dated 20 September 1968 with revisions dated 4 April 1969 and 23 May 1969.

e. Combat Damage Repairs for F-4C Aircraft, Report E213, dated 19 November 1965; McDonnel-Douglas report.

4.9.2 Aircraft Structure

"The aircraft structure shall be designed to be as damage tolerant as practical to minimize the vulnerability of the system to nonnuclear weapon effects. The level of protection shall be as required by the detailed contract specification which shall contain S/V specifications, or a level of protection requirement as dictated by survivability and system cost-effectiveness analyses."

4.9.2.1 Materials and Construction. "The materials and construction types selected for the airframe structure shall be selected with respect to the extent of damage that can be experienced from the hostile weapon effects. An analysis of the candidate structures shall be conducted to evaluate the extent of damage for each candidate structure and the amount of effort and cost that would be required for repair. Where the extent of repair is beyond the operational unit's authorization or capability, consideration shall be given to a structural design that will permit removal and replacement of a section of the airframe that is directly interchangeable with the same section on all of the same model aircraft. Sections of the structure that may be damaged by high explosive projectiles and small missile warheads, where there is a reasonable probability of aircraft recovery, shall be designed to be removable and replaceable with a minimum of maintenance effort. The use of special tools and fixtures shall also be avoided. It is essential to recognize the limitations of spare parts and repair material space allocations of organizational maintenance. The use of major structural section interchangeability will permit effective cannibalization to ensure that the greatest number of aircraft can be maintained in operational readiness during combat and peacetime operations. This concept will also minimize the number of damaged aircraft that must be disassembled, crated, and shipped for repair at higher echelon maintenance facilities."

4.9.2.1.1 "The basic structure shall also be designed to permit ready access for inspection of those areas most susceptible to damage. The structural provisions for electrical cabling and fluid (fuel, hydraulic, oil, etc.) lines shall be designed for rapid access, inspection, repair, or replacement.

4.9.2.1.2 "The aircraft structure shall be of a fail-safe design achieved through the use of multiple loadpaths and crack stoppers to reduce the probability of catastrophic structural failure due to battle damage. There shall be no flight critical structural components (e.g., primary wing, main rotor blades, flight control surfaces, etc.) vulnerable to a ______ projectile incurred in air-to-air/air-to-ground combat maneuvers, at representative weights, that would preclude a safe return and an arrested landing. Sufficient strength and redundancy to permit evasive maneuvers to limit load or delivery of remaining ordnance following the hit shall be provided if practical."

4.9.2.2 Airframe Protection. "The aircraft structure shall be of a fail-safe design achieved through use of multiple redundant loadpaths and crack stoppers to reduce the probability of catastrophic structural failure due to battle damage, i.e., structural damage which will cause loss of the aircraft.

4.9.2.2.1 "In compartments where liquids such as fuel, hydraulic fluid, oil, etc., are stored, the hydraulic ram effect due to impact energy of the ______ API projectile or ______HEI projectile shall be minimized by use of structural design techniques.

4.9.2.2.2 "Secondary thermal effects, as a result of projectile impact, shall be minimized throughout the entire airframe. These thermal effects include burning of fuel, hydraulic fluid, or oil; or "torching" from a damaged engine. The design must prevent fire and explosions in all areas of the airframe where failure to do so shall cause a forced landing.

4.9.2.2.3 "The design of the structure shall minimize secondary effects from exploding ammunition (caused by impacting enemy projectiles of any type) where failure to do so would result in an attrition or forced landing."

4.9.3 Battle Damage Repairability

"The design of the structural system shall incorporate those features that will enhance rapid repair of battle damage, especially for forward area maintenance operations."

4.9.3.1 "The basic structural design shall be such that repair of structural damage from ______ projectiles can be performed without requiring master jigging or special tools not normally found at a field maintenance facility.

4.9.3.2 "Component design shall be such that removal and replacement of battle damage components can be accomplished using primarily the general mechanics tool box and without special tools not normally found at a field maintenance facility and with a minimal number of personnel. Accessibility is also a prime design feature in reducing downtime.

4.9.3.3 "The selection of an aircraft structure, type of construction, and materials shall consider the time, skill level, special tools, and facilities required to effect battle damage repair. The types of fasteners used in structural designs shall be held to a minimum so that the stock of repair fasteners may be minimized. In areas of critical fastener locations in major structural elements such as forgings, castings, sculptured plates, etc., provisions shall be provided to permit the use of oversized or larger fasteners where battle damage may distort the original fastener hole. In structural areas where the greatest number of ballistic damage occurrences are expected, standard repair designs shall be developed that may be prefabricated and maintained in a combat area rapid repair kit to permit repairs in the minimum length of time. Such predesigned and prefabricated repair concepts shall consider the types and sizes of hostile threat damage mechanisms to which the aircraft may be exposed. The structure shall also be designed to limit the propagation of damage following the damage initially sustained. Techniques such as crack stoppers, high fracture toughness materials, and multi-loadpath designs should be considered. Careful consideration shall also be given to the selection of materials and protective coatings so that adequate corrosion control may be maintained following repair of battle damage.

4.9.3.4 "The use of nonmetallic (composite) structure shall be carefully analyzed to establish the means by which ballistic damage may be repaired under operational maintenance conditions. Where damage may be experienced that is beyond the capability or authorization of the operational maintenance unit, provisions shall be made for rapid removal and replacement of the damaged section. Composite materials must also be evaluated for their electromagnetic shielding effectiveness capabilities. This includes the shielding effectiveness of the bonding techniques.

4.9.4 Damage Tolerance

"The primary structure shall incorporate materials, stress levels, and structural configurations that will minimize the probability of loss of the aircraft due to damage of a single structural element (including control subsystem and dynamic components) or due to propagation of undetected flaws, cracks, or other damage. Slow crack growth, crack arrestment, alternate loadpaths and systems, and other available principles shall be used to achieve this capability. The specific requirement for damage to flight-essential structural components is that they shall preclude or accept damage from any ______ projectile and still be capable of supporting design limits without failure (yielding is allowed for this condition). The aircraft shall be capable of full continuous safe flight for (<u>30 minutes</u>).

4.9.4.1 "Damage to the critical airframe components and rotor blades from a ______ projectile should not cause catastrophic failure or preclude safe continuous flight to a normal destination where repairs can be made.

4.9.4.2 "Design features and techniques to reduce basic airframe vulnerability to impacting explosive projectiles of (23-mm) and (30-mm) shall be incorporated to the maximum extent practical."

4.9.4.2.1 "The primary structure of the aircraft shall be capable of sustaining single hits by ______ API type ______ and ______ HEI type ______ projectiles anywhere on the aircraft with the remaining structure having the capability of sustaining a ___ *g* limit load factor at ______ KIAS and the aircraft shall retain sufficient operating capability to safely return to its operational base.

4.9.4.2.2 "Structural vulnerability to single ___ -mm HE projectile detonations/fragment sprays shall be eliminated as much as possible through such means as redundant loadpaths and the arrangement of internal volumes and skin fasteners to minimize the effects of the blast.

4.9.4.2.3 "There shall be no flight-critical structural components vulnerable to single hits by API projectiles up to and including ______ type ______ and by ___ -mm HEI projectiles.

4.9.4.2.4 "Structural vulnerability to low-order detonations of ordnance carried internally in the ammunition drum of the aircraft shall be reduced or eliminated to the maximum extent possible.

4.9.4.2.5 "The aircraft shall not suffer catastrophic structural failure due to the penetrations of and dynamic loadings within/upon internal fuel tanks caused by single hits by API projectiles up to and including ______ and by ______ projectiles. This includes three damage mechanisms: hydraulic ram effects, ullage explosions with resulting overpressures, and detonation of high explosive projectiles. The aircraft shall have the capability of sustaining a ___ g limit load factor at V = ___ after suffering such structural damage."

4.9.5 Airframe Armor

"Airframe armor shall be provided if required to supplement personal and seat armor to protect crewmen through the entire bottom hemisphere while the aircraft is in level flight. Maximum upper hemisphere protection should be provided for fragments.

"Transparent armor of sufficient strength to defeat the fragmentation and survive the blast of an exploding ______ projectile shall be placed between the crewmembers in multi-crew aircraft to preclude incapacitation of more than one crewman from a single projectile. Nontransparent armor may be used as a barrier between crewmembers in those areas not affecting the aft crewman's external vision envelope."

Note: Detailed armor specification statements are presented in Section 4.16, Crew Stations.

4.9.6 Windshields and Windows

"A windshield shall be provided for the cockpit enclosure. Windshields shall be shatterproof and able to safely withstand the airloads imposed by the flight requirements specified herein. Surfaces in contact with windshield wipers shall be of inorganic glass and shall not scratch if the windshield wiper is activated on a dry windshield. In the selection of materials, consideration should be given to minimize wounding of personnel by spall from impacting projectiles. Windshields and windows shall provide a degree of shielding effectiveness consistent with airframe requirements."

Note: Additional windshield requirements are given in Section 4.16.

4.10 LAUNCH AND RECOVERY SYSTEMS

These units and components furnish a means of supporting and steering the aircraft on the ground or water and make it possible to retract and store the landing gear in flight. The launch and recovery systems also include those mechanical, hydraulic, and electrical components used for control and operation of the arresting gear and catapult gear.

The landing gear system includes the following components:

a. Wheels.
b. Floats.
c. Skids.
d. Tailskin assembly.
e. Skis.
f. Brakes.
g. Shock struts.
h. Drag struts.
i. Bogie axles.
j. Doors.
k. Linkages.
l. Attach bolts.
m. Tires.
n. Position indicating and warning system.
o. Actuating mechanisms.
p. Bungees.
q. Latches.
r. Valves.
s. Motors.
t. Cables.
u. Antiskin devices.

The catapult and arresting gear systems consist of:

a. Arresting hook point and shank.
b. Catapult hook and hold back.
c. Pulleys.
d. Cables.

e. Cylinders.
f. Accumulators.
g. Valves.

The landing gear components are vulnerable to the penetration weapon effect of projectiles and fragments. In addition, components operated by hydraulic fluid are vulnerable to hydraulic ram and the fluid, the tires, and some of the mechanical linkage components are vulnerable to the fire secondary kill mechanism.

The key variables in the specification of survivability for the launch and recovery systems are those that define the threat and its kill mechanisms. The kill criteria must be carefully specified since there is an E-kill that relates primarily to damage to the landing and arresting gears.

Additional specification variables which could affect the vulnerability of the launch and recovery systems, and therefore must be considered, are contained by Appendix A.

Sample vulnerability reduction requirements statements for the launch and recovery system are given in subsequent paragraphs.

4.10.1 Landing Gear

"The landing gear system shall be designed to provide a simple and reliable means to extend and lock the wheels (and tail hook) in position when the normal system has been damaged by hostile weapon effects.

4.10.1.1 "The launch/recovery systems shall incorporate design features that minimize as much as practical, loss of mission critical functions due to a single hit from:

a.____-mm (API or API-T), Type___projectile impacting at a velocity of___ft/sec.
b.____-mm (HEI or HEI-T), Type___projectile impacting at a velocity of___ft/sec.
c.____-grain fragments impacting at a velocity of___ft/sec.

4.10.1.2 "System design shall ensure, as a minimum, emergency extension of landing gear (and tail hook) after receiving a single hit from:

a.____-mm (API or API-T), Type___projectile impacting at a velocity of___ft/sec.
b.____-mm (HEI or HEI-T), Type___projectile impacting at a velocity of___ft/sec.
c.____-grain fragment impacting at a velocity of___ft/sec.

4.10.1.3 "The landing gear subsystem shall be located to minimize the possibility that a part of the gear or support structure will be driven into an occupiable section of the aircraft, or into a region containing a flammable fluid tank or line, in any accident falling in the survivable category as defined in TR 71-22. Failure of the landing gear shall not result in a failure of any crew seat restraint system or restraint system tiedown.

4.10.1.4 "The components of the landing gear system shall be designed to minimize secondary damage when impacted. Items such as emergency pneumatic extension air bottles, however, can explosively shatter when impacted by a ballistic threat and can cause considerable secondary damage to nearby components and structure. Consideration shall be given to the design of such pressure vessels to minimize such reaction. Filament winding of non-metallic material around an inner metallic air bottle is one example of a nonshatterable container. Attaching brackets for smaller components within the landing gear, nose gear steering, wheel brake, arresting gear, or drag chute systems shall be designed to be damage tolerant and repairable rather than brittle and unrepairable when subjected to battle damage."

4.10.2 Combat Damage Repair Considerations

"Considerations shall be given to the location and accessibility of those components in the landing and launching systems that are most susceptible to primary and secondary damage mechanisms. Consideration shall be given to design of main landing gear struts and components that are interchangeable for either right- or left-hand installation to minimize the number of spare parts to be carried."

4.11 ARMAMENT SYSTEM

The armament system consists of those units and components which store, support, and fire or release ammunition or other internally carried or externally carried stores. Included in the armament system are:

a. Installed launchers and related mechanisms.
b. Ammunition feed and ejection mechanisms.
c. Gun Systems.
d. Hoists.
e. Slings.
f. Sway braces.
g. Racks.
h. Releases.
i. AEC equipment.
j. Ammunition storage containers.

The load-carrying or reacting components of the armament system are vulnerable to the severing or cross section reduction resulting from penetration by projectiles or fragments. The release, feed, and eject mechanisms are also vulnerable to jamming or blocking caused by deformation of the components. Pyrotechnics in the release or ejection mechanisms are vulnerable to kinetic energy weapons (the conversion of kinetic to thermal energy) and to the secondary mechanism of fire. The principal hazard of the ammunition system is the generation of the secondary kill mechanisms of heat (fire), overpressure and, in the case of high order detonations, fragments caused by burning propellants or exploding projectiles. Ammunition is vulnerable to both kinetic energy projectiles and high explosive projectiles as well as fire within the aircraft.

The specification of survivability requirements for the armament system and its components must contain a definition of the threat which must be survived and the kill mechanisms of this threat. If armor protection is to be provided for the ammunition system, the armor design requirements must be specified in the same manner as for crew system protection (see Section 4.16).

Additional specification variables which could affect the vulnerability of the armament system, and therefore must be considered, are contained in Appendix A.

Sample vulnerability reduction requirements statements for the armament system are given in subsequent paragraphs.

4.11.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-A-8591.
b. MIL-W-13855.
c. MIL-STD-1512.
d. MIL-C-83124.
e. MIL-C-83125.

4.11.2 Aircraft Structural Considerations

"The design of the aircraft structure shall minimize secondary effects from exploding ammunition caused by impacting projectiles of any type where failure to do so would result in loss of mission or flight-essential functions or capabilities."

4.11.3 Armament Storage

"Consideration shall be given to the location and configuration of ordnance carriage on an aircraft system to minimize the secondary damage that may be generated from the response of ammunition, missiles, rockets, bombs, flares, etc., to direct ballistic impact. Those carried internally are generally those whose reaction to battle damage will have the capability of producing additional damage that would increase the repair problem. In such installations, consideration shall be given to means of limiting the spread of damage by shielding or insulation. Provision for rapid jettison of burning ordnance, where continued carriage would cause additional aircraft damage, shall be considered."

4.11.4 Armament System Design

4.11.4.1 "The armament system shall incorporate design features to prevent loss of aircraft due to fire or explosion of internally carried ammunition due to single hits from:

a. ____-mm (API or API-T), Type _____ projectile impacting at a velocity of ____ ft/sec.
b. ____-mm (HEI or HEI-T), Type _____ projectile impacting at a velocity of ____ ft/sec.
c. ____-grain fragments impacting at a velocity of ____ ft/sec.

4.11.4.2 "Provisions shall be incorporated to delay the hazardous response of the aircraft internal armament loadings when subjected to JP-4, JP-5, (or NATO fuels) fuel fires on a carrier flight or hangar deck."

4.11.4.3 "The avionics and wiring for armament weapon control, fuze function control, and special weapons shall be designed for rapid access inspection, repair, or replacement."

4.11.4.4 "Armor may be required for protection of internal stores. If so, the requirements statements of Section 4.16 should be used, as applicable."

4.11.4.5 "The armament system shall incorporate design features to reduce its vulnerability to external friendly and hostile electromagnetic environments."

4.12 ENVIRONMENTAL CONTROL SYSTEM

The environmental control system includes the subsystems used in air conditioning and ice and rain removal (the oxygen system is considered as a separate system).

a. Air-conditioning system – those units and components which furnish a means of pressurizing, heating, cooling, moisture controlling, filtering, and treating the air used to ventilate the areas of the fuselage and equipment bays within the pressure seals. Typical components of the air-conditioning system are:

   1. Supercharger.
   2. Equipment cooling.
   3. Heater.
   4. Heater fuel system.
   5. Expansion turbine.
   6. Valves.
   7. Scoops.
   8. Ducts.
   9. Blowers.
   10. Filters.

b. Ice and rain removal system – those units and components which dispose of rain and prevent or dispose of ice formations.

   1. Alcohol pump.
   2. Valves.
   3. Tanks.
   4. Propeller/rotor anti-icing system.
   5. Wing heaters.
   6. Water line heaters.
   7. Pilot heaters.
   8. Scoop heaters.
   9. Windshield wipers.
   10. Windshield ice control system.

The environmental control systems affect survivability through the degradation of the performance of other systems resulting from the loss of the functional capabilities of the environmental control systems and from secondary hazards resulting from damage to the system. For example, any system that requires heated or cooled air or that needs heat to control or prevent icing may lose its capability if the environmental control system cannot provide its required services.

Any of the air distribution or management systems are vulnerable to penetration by projectiles or fragments and to high explosive projectiles in, on, or adjacent to the components. If a separate fuel supply is required, it has the same vulnerability characteristics and requirements as discussed in Section 4.2.

The primary variables which must be included in the survivability specification for environmental control systems are those that define the threat and its kill mechanisms. The survivability requirements for the environmental control system should also reflect the functional requirements of the system that are supported with conditioned air, heat, etc. and the effect of the loss of the functions of these supported systems.

Additional specification variables which could affect the vulnerability of the environmental control system, and therefore must be considered, are contained in Appendix A.

Sample vulnerability reduction requirements statements for the environmental control system are given in subsequent paragraphs.

4.12.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-D-19326.
b. MIL-D-8683.
c. MIL-E-18927.
d. MIL-H-18325.
e. MIL-STD-890.

4.12.2 Environmental Control System Design Considerations

"The environmental control system shall be designed to minimize creation of hazardous conditions for the aircrew and essential components from nonnuclear weapon effects."

4.12.2.1 "The environmental control system shall incorporate design features that minimize the routing of high temperature bleed air through compartments containing combustibles or void spaces adjacent to such compartments. Compartments containing routing of high temperature bleed air in which combustibles are located or routed shall incorporate fire protection measures as approved by the procuring agency when perforation of the high temperature bleed air line can be caused by single hits from:

a. ____mm (API or API-T), Type______ projectile impacting at a velocity of___ ft/sec.
b. ____mm (HEI or HEI-T), Type______ projectile impacting at a velocity of___ ft/sec.
c. ____grain fragments impacting at a velocity of____ ft/sec."

4.12.2.2 "The use of hot gas systems in an aircraft shall be minimized to prevent damage to structure or other sensitive subsystem components from punctured hot gas ducts or equipment. Where such systems cannot be avoided, provisions shall be made to permit shut-off of the hot gas as close to the source as possible. The ducting for these systems shall be designed to permit rapid removal or repair for battle damage."

4.12.2.3 "The environmental control system shall incorporate design features to reduce its vulnerability to external friendly and hostile electromagnetic environments."

4.12.3 Combat Damage Repairability

"Battle damage repair is predominately concerned with removal and replacement. For these items, the main consideration shall be ready access for inspection and replacement. The ducting in some systems may be of a size and type of construction that lends itself to repair. For this possibility, the capability to repair in place as well as to remove, repair, and replace shall be considered. In the installation of lines, care shall be exercised to position connectors so that removal and replacement of damaged sections may be accomplished with a minimum disturbance of other components or structures."

4.13 ELECTRICAL POWER SYSTEM

The electrical power system includes those units and components which generate, control, supply, and distribute AC or DC electrical power for other systems. Typical components of the electrical power system are:

a. Inverters.
b. Generators.
c. Alternators.
d. Control and regulating components.
e. Transformers.
f. Rectifiers.
g. Batteries.
h. Indicating systems.
i. Relays.
j. Receptacles.
k. Switches.
l. Warning lights.
m. Main buses.
n. Secondary buses.
o. Main system circuit breakers.
p. Power system devices.
q. Wiring.

The vulnerability of the electrical system components is due to the severing or grounding of electrical circuits, the destruction or unbalancing of rotating components such as generators or alternators, and the penetration or overheating of batteries. The system is, therefore, vulnerable to both projectiles and fragments and to the secondary damage mechanism of fire which can burn through, melt, or fuze the components of the system.

The survivability specification for the system must identify the threat that must be considered. It must also specify the redundancy requirement for the system in terms of the number of damaging hits the system must be able to take without a loss of its functional capability or the generation of a secondary ignition hazard.

Additional specification variables, which could affect the vulnerability of the electrical power system, and therefore must be considered, are given in subsequent paragraphs.

4.13.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-E-25499.
b. MIL-W-5088.
c. MIL-STD-1631.

4.13.2 Electrical System Survivability Design Considerations

"Survivability shall be designed into the subsystems so that no single electrical failure will cause failure of any system essential to flight.

4.13.2.1 "The electrical power system shall be protected against complete electrical power failure due to a single hit from:

a. ____-mm (API or API-T), Type _____ projectile impacting at a velocity of ___ ft/sec.
b. ____-mm (HEI or HEI-T), Type _____ projectile impacting at a velocity of ___ ft/sec.
c. ____-grain fragment impacting at a velocity of ___ ft/sec."

4.13.2.2 "The electrical power system shall incorporate features to minimize, as much as practical, loss of mission critical functions due to single hits from:

a. ____-mm (API or API-T), Type _____ projectile impacting at a velocity of ___ ft/sec.
b. ____-mm (HEI or HEI-T), Type _____ projectile impacting at a velocity of ___ ft/sec.
c. ____-grain fragment impacting at a velocity of ___ ft/sec.

4.13.2.3 "Primary/backup system equipment and power distribution routing shall be physically separated to preclude damage to more than one system from a single hit by the ______ projectile."

4.13.2.4 "The electrical power system shall incorporate design features to reduce its vulnerability to external friendly and hostile electromagnetic environments."

4.13.3 Component Considerations

"Circuits for essential functions shall be given priority for protection and safeguard provisions. Hazardous circuits shall be isolated from potential sources of short circuit actuation or failure from primary or secondary weapon effects. Multiple/cascading failures in electrical bus systems shall be avoided. Electrical system component locations and routings shall be designed to avoid areas of highest secondary damage effects potential. Provisions shall also be incorporated to permit rapid access for inspection and repair."

4.13.4 Electrical Boost

"The survivability design criteria applicable to hydraulic power or boost shall apply. Singly vulnerable components shall be duplicated and separated or protected by some other means. Caution should be exercised in design of new or different subsystems to prevent the vulnerability reduction of one component from creating a significant increase in the vulnerability of another component or subsystem."

4.13.5 Combat Damage Repair Considerations

"In the detail design of electrical power and distribution systems, consideration shall be made to permit standard repairs to be developed for wiring, cabling, and connector points. There shall be sufficient room to permit damaged connector replacement without excessive removal or other components or structure. Where electrical power system wiring enters or exits in a modular section of the aircraft, connectors shall be provided that permit removal and replacement of a damaged module with an interchangeable section. This applies particularly to fuselage, wing, and empennage sections. The installations of electrical power equipment shall permit rapid access, removal, and replacement. The allocation of spare parts for components which have high probability of damage shall be increased for combat operations."

4.14 AVIONICS SYSTEM

The avoinics system consists of a number of subsystems, each with its own set of components and functions. Typical subsystems of the avionics system are:

a. HF communications.
b. VHF communications.
c. UHF communications.
d. Miscellaneous communications.
e. Interphone.
f. IFF.
g. Emergency radio.
h. Communication-Navigation-IFF integrated package.
i. Radio navigation.
j. Radar navigation.
k. Bombing navigation.
l. Weapons control system
m. Electronic countermeasures.
n. Photographic reconnaissance.
o. Instruments.
p. Autopilot.
q. Flight reference system.
r. Integrated guidance and flight control.

Avionics systems are normally vulnerable to nearly all of the conventional weapon kill mechanisms and weapon effects. Many are susceptible to damage of functional degradation as a result of exposure to the electromagnetic pulse (EMP) resulting from the detonation of nuclear weapons. They are also vulnerable to secondary damage effects such as fire, spall, hot gas torching, loss of cooling, and loss of power.

Additional specification variables which could affect the vulnerability of the avionics system, and therefore must be considered, are contained in Appendix A.

With the exception of protection from EMP, which can be highly influenced by deisgn, protection for avionics systems is usually through miniaturization, location, and ballistic shielding and through the protection of functional capability through redundancy. The threat should be identified along with the critical avionics system functions that are to be protected.

Sample vulnerability reduction requirements statements for the avionics system are given in subsequent paragraphs.

4.14.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-I-8700.
b. MIL-STD-1389.
c. MIL-STD-188.

4.14.2 Avionics Systems Survivability Design Considerations

"Military avionics equipment is highly susceptible to ballistic damage. It also generally exhibits the longest delay to obtain replacement parts in combat operations. Consideration shall be given to placement of the more complex and expensive avionics equipment in areas that are less likely to be exposed to hostile weapon effects.

4.14.2.1 "The avionics system, including interconnecting wiring shall incorporate design features that minimize as much as practical loss of mission-critical or flight-safety functions due to a single hit from:

a. ____-mm (API or API-T), Type _____ projectile impacting at a velocity of ___ ft/sec.
b. ____-mm (HEI or HEI-T), Type _____ projectile impacting at a velocity of ___ ft/sec.
c. ____-grain fragment impacting at a velocity at ___ ft/sec.

4.14.2.2 "Those avionics systems which are critical for continued flight shall be protected against single hits by:

a. ____-mm (API or API-T), Type _____ projectile impacting at a velocity of ___ ft/sec.
b. ____-mm (HEI or HEI-T), Type _____ projectile impacting at a velocity of ___ ft/sec.
c. ____-grain fragment impacting at a velocity of ___ ft/sec.

4.14.2.3 "Provisions to delay failure from loss of normal environmental conditions shall be considered so that operations can be performed even in degraded modes."

4.14.2.4 "The avionics systems shall incorporate design features to reduce their vulnerability to external friendly and hostile electromagnetic environments."

4.14.3 Combat Damage Repairability

"Experience has shown that significant inspection and failure diagnostic time has been required to isolate malfunctioning avionic units or wiring. Consideration shall be given to the overall design of avionics systems to minimize the time and effort required to identify the damaged unit(s).

4.14.3.1 "The design of avionic equipment installation shall consider means to permit rapid removal of single components or modular sections of an assembly to permit inspection and repair of the bay.

4.14.3.2 "Connecting electrical cabling shall be designed to be accessible for repair or replacement without need of major structural disassembling.

4.14.3.3 "All instruments should be removable from the front of the panel.

4.15 FIRE PROTECTION SYSTEM

The fire protection system consists of those fixed and portable units and components which detect and indicate fire or smoke and distribute fire extinguisher agents to protected areas of the aircraft. Typical components are:

a. Detectors.
b. Bottles.
c. Valves.
d. Tubes.
e. Indicating systems.

The loss of the fire protection system does not in itself result in a degradation of vehicle or mission performance. Loss of the system increases the probability of a sustained fire given damage to another system which either contains combustibles or becomes an ignition source.

Additional specification variables which could affect the vulnerability of the fire protection system, and therefore must be considered, are contained in Appendix A.

The components of the system are primarily vulnerable to the penetration and severing effects of projectiles and fragments. The survivability specification should include the identification or definition of the threat. It should also include any requirements for multiple employments of the system after damage.

Vulnerability reduction requirements for the fire protection system are closely related to the propulsion system and propulsion system installation requirements and should to thoroughly coordinated with the requirements for these systems.

Sample vulnerability reduction requirements statements for the fire protection system are given in subsequent paragraphs.

4.15.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-C-22284.
b. MIL-E-22285.
c. MIL-D-27729.
d. MIL-F-23447.
e. MIL-F-7872.

4.15.2 Fire Protection System Survivability Design Considerations

4.15.2.1 "A highly reliable and survivable fire detection system plus fast acting, multiple-shot fire extinguishers shall be installed in each engine compartment/nacelle.

4.15.2.2 "The system shall be capable of performing its functions after any single hit by the______projectile impacting at a velocity of___ft/sec.

4.15.2.3 "The fire protection system shall incorporate design features to reduce its vulnerability to external friendly and hostile electromagnetic environments."

4.16 CREW STATION AND PASSENGER COMPARTMENT

Crew station and passenger compartment protection for nonnuclear threat weapons involve, primarily, the defeat of their penetration and impact capabilities and protection from the spall or debris which results from projectile or fragment impact and penetration.

Additional specification variables which could affect the vulnerability of the crew station and passenger compartments, and therefore must be considered, are contained in Appendix A.

Sample vulnerability reduction requirements statements for the crew station and passenger compartment are given in subsequent paragraphs.

4.16.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003, Documentation of Survivability/Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-I-8675.
b. MIL-A-19879.
c. MIL-C-18491.
d. MIL-STD-1288.
e. MIL-B-43366.
f. MIL-E-9426.
g. MIL-G-5485.
h. MIL-S-18471.
i. MIL-S-58095.
j. MIL-S-9479.
k. MIL-STD-1511.

4.16.2 Crew Station

"The (pilot/aircrew) and critical components shall be protected at all aspects, excluding the canopy and windshield areas, against the following threats.

a. (Single, multiple) hits by the___-mm AP (or API), Type___projectile impacting normal to the skin at___ft/sec.

b. (Single, multiple) hits by the___-mm HE (HEI or HEI-T), Type___projectile with___fuze impacting normal to the skin at___ft/sec.

c. (Single, multiple) hits by a___-grain fragment with (hardness scale, value) hardness impacting normal to the skin at___ft/sec."

4.16.2.1 Windshields and Canopy

4.16.2.1.1 "The front windshield panel will be designed to defeat the___-mm API, Type ______ projectile impacting at ___° obliquity. Backface spall protection will be provided for the front windshield to protect the (pilot/aircrew) from windshield fragments resulting from the above threat and from a 4-pound bird impacting at the level flight maximum speed of the aircraft at sea level.

4.16.2.1.2 "If front-panel and quarter-panel windshields are employed, they shall have transparent spall protection on the back face to contain the pieces of the impacted windshield panels and to minimize injury to the (pilot/aircrew) due to windshield fragments.

4.16.2.1.3 "The canopy shall be a spall resistant material.

4.16.2.1.4 "The windshield(s) and canopy shall be designed with minimum of curved surfaces to minimize the visual signature from reflected light and to minimize distortion."

4.16.2.2 Armor

"Parasitic or integral armor shall be used to protect the crew station and other critical components of the aircraft only when adequate protection cannot be provided through other design approaches.

4.16.2.2.1 "Armor design and the design of front windshield panels, for all threat projectiles, will employ the following design criteria."

4.16.2.2.1.1 "Ballistic protection shall be provided for the (V_{05}, V_{50}) level. This is the velocity for a specified penetrator for which there is a (95, 50) percent confidence level that no complete penetration of the armor system will occur.

4.16.2.2.1.2 "The slant range distance between the ground-based gun and the aircraft shall be ___ feet.

4.16.2.2.1.3 "The aircraft velocity vector shall be ___ (feet, meters) per second aligned along the aircraft's longitudinal axis.

4.16.2.2.1.4 "All aircraft attitudes shall be considered.

4.16.2.2.1.5 "Except where specified, components that are required to be invulnerable to a given threat projectile shall be protected/shielded over the full sphere of impact directions.

4.16.2.2.1.6 "Armor designed to defeat a given threat projectile shall be dynamically sized to account for the relative motion between the projectile and the aircraft (i.e., accounting shall be made for the aircraft velocity, the projectile striking obliquities and velocities, yaw induced into the projectile at impact, and the tipping or tumbling trajectory changes due to projectile contact with the aircraft skin or other surfaces).

4.16.2.2.1.7 "If titanium is used as integral armor, provisions shall be made for the possible future installation of lines, ducts, cables, or wire bundles for added aircraft subsystems. If access holes are provided for future use, the holes will be capped and hardened to the same ballistic protection level as the material they replace.

4.16.2.2.1.8 "Battle damaged integral or parasitic armor materials, which are repaired, will be restored to their original structural load-carrying capacity, if any, and to not less than ___ percent of their original ballistic protection limit.

Note: If a "Combat/Battle Damage Repair Manual" (C/BDRM) is prepared, it shall include the following two requirements.

4.16.2.2.1.9 "The contractor will include in the C/BDRM, a detailed description, with illustrations, of the procedures and techniques needed to perform in-field and depot-level battle damage repair of all armor and spall-suppression material used in the aircraft. The C/BDRM will specify under what conditions and degrees of battle damage the integral or parasitic armor materials should be repaired in-field or left for depot-level repair.

4.16.2.2.1.10 "Where tapered, milled, or sculptured integral or parasitic armor materials are used, the C/BDRM will include:

a. A description of the procedures and techniques for in-field and depot-level repair and restoration of the damaged armor material including the milling equipment and methods to be used.

b. A designation of constant gauge aluminum or titanium materials of equivalent ballistic protection, which can be directly substituted in-field for battle-damaged nonconstant gauge armor materials and which describe the mounting or installation techniques needed to compensate for this armor substitution."

4.16.2.3 Armored Trade Studies (See Section 2.6.2.)

4.16.2.4 Armored Seats

"If armor-protected seats are required, they shall incorporate the following characteristics.

a. Ease of installation and removal using a standard mechanics tool set.

b. Maximum protection for the head, neck, and torso areas of the crewman's body (exclusive of the chest area and forward hemisphere) against the ______ projectile impacting at ____ (feet or meters)/second at ____° obliquity.

c. No interference with vision or with the operation and accessibility of crew station controls.

d. Minimum weight penalty."

4.16.2.5 Crew Compartment Lighting

"Cockpit crew compartment lighting shall be designed to eliminate or minimize the possibility of detection of the light by a ground observer."

4.16.2.6 Crew Station Battle Damage Repairability

"Crew stations in an aircraft contain many sensitive instruments, components, and transparencies and should be designed to minimize the generation of secondary fragments or spall from ballistic penetrators (projectiles or fragments). These elements shall be identified so that they can be considered for protection and so that consideration may be given to design methods which allow removal and replacement of such items rapidly either individually or as a part of a crew station unit. Provisions shall be made to permit rapid removal of instrument panels, equipment, or secondary structures to gain access to electrical cabling, environmental controls, etc., for replacement or repair.

"Transparency material selection and design shall minimize the possibility of explosive shattering when impacted by a ballistic penetrator. Ballistic damage to transparencies normally requires direct replacement. They shall, therefore, be designed to permit such replacement with a minimum of tooling, man-hours, and cost."

(The following requirement is applicable if the aircraft is to be operated from the deck of an aircraft carrier.)

4.16.2.7 Fire Engulfment Protection

"The cockpit area shall be designed to protect the (pilot/aircrew) for (5 minutes) from a carrier deck fire of ___° (Fahrenheit, Celsius) engulfing the aircraft."

4.16.3 Passenger Compartment

"The passenger compartment shall be protected from the ___-grain fragment threat impacting normal to the skin of the aircraft at an impact velocity of ___ (feet or meters) per second."

4.17 OXYGEN SYSTEM

The oxygen system consists of those units and components which store, regulate, and deliver oxygen to the crew and passengers. Those components include:

a. Bottles.
b. Relief valves.
c. Shutoff valves.
d. Outlets.
e. Regulators.
f. Masks.
g. Lines.

As a storage and distribution system for a pressurized fluid, the oxygen system is vulnerable to anything that will cause a perforation or severing of the system. The pressure vessels in themselves can be the source of secondary kill mechanisms if they are susceptible to explosive disintegration when damaged. The pressurized oxygen also compounds any fire hazard.

The kill mechanisms to which the system is vulnerable include both kinetic energy and explosive projectiles, fragments, and blast (either directly on the components or through any structural deformation that will sever or rupture an oxygen line). The system is also extremely vulnerable to the secondary kill mechanism of fire within the aircraft and may be vulnerable to secondary spall mechanisms.

The oxygen system survivability specification may either be one in which the threat and its kill mechanisms are defined (protection or the system is required for this threat) or the requirement may be to protect the remaining systems through isolation or containment of any secondary kill mechanisms or weapon effects which could result from damage to the system.

Additional specification variables which could affect the vulnerability of the oxygen system, and therefore must be considered, are contained in Appendix A.

Sample vulnerability reduction requirements statements for the oxygen system are given in subsequent paragraphs.

4.17.1 Applicable References

Applicable references for the survivability and design of the subsystem are given below. Reference should also be made to report JTCG/AS-74-D-003. Documentation of Survivability Vulnerability Related Aircraft Military Specifications and Standards.

a. MIL-D-19326.
b. MIL-D-8683.

4.17.2 Vulnerability Reduction for the Oxygen System

4.17.2.1 "Design of the crew oxygen system shall be such as to ensure that loss of the aircraft does not occur due to a single hit from:

a.____-mm (API or API-T), Type______ projectile impacting at a velocity of___ft/sec.
b.____-mm (HEI or HEI-T), Type______ projectile impacting at a velocity of____ft/sec.
c.____-grain fragment impacting at a velocity of____ft/sec.

4.17.2.2 "Oxygen containers shall be located to minimize the amount of damage that may be generated to other systems of the aircraft structure if ruptured by ballistic damage.

4.17.2.3 "Oxygen lines shall be isolated from all combustibles, particularly liquid combustibles such as fuel, hydraulic fluid, and lubricating oil."

4.18 MISCELLANEOUS SYSTEMS

There are several additional aircraft systems which are frequently ignored in the survivability specification for an aircraft or its systems. These systems and their components should be reviewed, however, to determine the effect of the loss of their functions on the aircraft and to determine whether or not their damage can result in the generation of secondary kill mechanisms (spall, fire, ignition sources, etc.). Some of these additional systems and typical components of each are as follows:

a. Vacuum system – those units and components used to generate, regulate, and deliver negative air pressure, including:

   1. Pumps.
   2. Regulators.
   3. Lines.
   4. Manifolds.
   5. Pressure indicating systems.
   6. Warning systems.

b. Lighting system – those units and components that provide external and internal illuminations, such as:

   1. Bulbs.
   2. Light fixtures.
   3. Switches.

4. Wiring.
5. Landing lights.
6. Navigation lights.
7. Position indicating lights.
8. Wing illumination.
9. Rotating beacon.
10. Courtesy lights.
11. Taxi lights.
12. Inertia flashlights.

c. Emergency survival equipment – those units and components that are provided to enhance the crew/passenger probability of survival given the ejection or egress from an aircraft in flight or the ditching or crash landing of the aircraft, including:

1. Parachutes.
2. Life rafts.
3. First aid kits.
4. Pyrotechnics.
5. Fire extinguishers.
6. Fire axes.
7. Emergency lights.
8. Emergency exit ladders.
9. Aviators' clothing.
10. Helmets.
11. Oxygen masks.
12. Bailout bottles and regulators.
13. Communication equipment.
14. Radiation/thermal shields.

d. Escape system – includes the units and components of the ejection seat/capsule system:

1. Seats.
2. Rails.
3. Canopy breakers.
4. Sequencing devices.
5. Controls.
6. Retract/restraint devices.
7. Ejection cartridges.
8. Rockets.
9. Cartridge activation devices.
10. Protective enclosure.
11. Ground safety devices.

e. Starting system – those units, components, and associated systems used in the starting of the engine, including:

1. Electrical, inertial air, or other starting systems.
2. Plumbing.
3. Valves.

4. Wiring.
5. Switches.
6. Relays.

f. Emergency power systems includes ram air turbines, hydraulic-driven emergency electrical power units, and hand-driven emergency hydraulic power systems.

1. Ram air turbine.

    a. Extension and retraction cylinders.
    b. Control valves.
    c. Reservoirs.
    d. Handles.
    e. Cables.
    f. Pulleys.
    g. Springs.
    h. Switches.
    i. Warning lights.
    j. Hydraulic power units:

        - Hydraulic pumps.
        - Regulator valves.
        - Bypass valves.
        - Control valves.
        - Pressure switches.
        - Pressure transmitters.

    k. Electric power units:

        - Generators.
        - Voltage regulators.
        - Transformer rectifiers.
        - Transfer relays.
        - Wiring.

2. Hydraulic-driven emergency electrical power unit:

    a. Motor generators.
    b. Hydraulic motors.
    c. Motor generator regulators.
    d. Transfer relays.
    e. Undervoltage regulators.
    f. Bus control relays.
    g. Wiring.

3. Hand-driven emergency hydraulic power system:

    a. Reservoirs.
    b. Hand pumps.
    c. Filters.

d. Relief valves.
e. Check valves.
f. Lines.

g. Airborne auxiliary power system - those airborne powerplants (engines) which are installed on the aircraft for the purpose of generating and supplying a single type or combination of auxiliary electric, hydraulic pneumatic, or other power.

1. Power and drive section.
2. Fuel.
3. Ignition.
4. Control systems.
5. Wiring.
6. Indicators.
7. Plumbing.
8. Valves.
9. Ducts.

Each of the components of these miscellaneous systems is vulnerable to one or more of the threat weapon kill mechanisms and, if the functional capability of the component is required for aircraft survival, a survivability specification statement should be developed. In general, these survivability specification requirements can be patterned after those of similar components in the primary systems.

Additional specification variables which could affect the vulnerability of these miscellaneous systems, and therefore must be considered, are contained in Appendix A.

5.0 REQUIREMENTS FOR NUCLEAR VULNERABILITY REDUCTION

Aircraft subsystems and components, and therefore the total aircraft system, are vulnerable to nuclear weapon effects. If a hostile nuclear weapon threat exists, or if the aircraft can potentially be exposed to nuclear effects from its own weapons or weapons of friendly forces, then nuclear protection requirements shall be considered in the preparation of the survivability specification.

The material presented in this section is organized by weapon effects. The requirements statements that are presented represent both general and specific requirements.

Representative general paragraphs and sample statements have been supplied in this section for use in aircraft procurements and represent varying levels of survivability/vulnerability (S/V) requirements involved in the design. Each of these representative paragraphs and sample statements is provided to serve as a guideline only, and is to be used only after appropriate tailoring or modification to meet the needs of the specific procurement specification for nuclear vulnerability reduction.

5.1 GENERAL STATEMENT

"The aircraft system shall be designed to withstand the levels of hostile nuclear weapon effects required by the S/V specification and the statement of work. These values shall be mission completion levels required for delivery of the aircraft weapons upon the specified target in a nuclear conflict."

5.1.1 Relationship of Requirements to Mission Phases

"Environmental elements are applicable in varying degrees during each mission phase; therefore, the nuclear environments and effects shall be related to the mission phases as appropriate. These are as follows:

a. Thermal and blast – penetration/combat and weapon delivery/withdrawal.

b. Transient radiation effects on electronics (TREE) – total ionizing dose following landing gear retraction through recovery.

c. TREE – prompt dose (dose rates) and neutron fluence during penetration/combat and weapon delivery/withdrawal.

d. Electromagnetic Pulse (EMP) – from parked on noncockpit alert through recovery."

5.1.2 Typical Helicopter Requirement with Restricted Hardening Applications

"There are several important guidelines to consider in the development of a responsive nuclear hardening plan. They are:

a. Nuclear encounters are extremes of military expectation and for aircraft should not be considered a normal event (i.e., nuclear encounters are unlikely to occur in everyday application of the materiel). The weight and cost penalties of hardening to that criteria (sure-safe) are unwarranted for aircraft at this point in time.

b. The aircraft should be hardened to a "mission completion" kill criteria. Specifically the aircraft should be capable of surviving to the criteria listed below after being subjected to nuclear effects as outlined for two levels in the classified specification attachment:

1. Shall be capable of continued safe operation for at least (30 minutes) after damage received during the following modes:

   a. In-flight hovering – maximum load.
   b. In-flight cruise – maximum load.
   c. In-flight cruise – minimum load.

2. Shall be capable of completing at least (30) primary mission flights following a period of (24 hours) of elapsed time for repairs after sustaining damage effects during the following modes:

a. Parked prepared for attack.
b. Parked prepared for flight.
c. In-flight hovering – maximum load.
d. In-flight cruise – maximum load.
e. In-flight cruise – minimum load.

The performance degradation for which the above conditions can be met (e.g., permissible load, speed, hover, landing, and takeoff characteristics) should be results of the hardening analysis.

c. The plan should consider the combined influence on aircraft due to nuclear effects according to:

1. Transient response at the time of loading of:

a. In-flight stability
b. Structural components.
c. System components.
d. Passenger/payload.

2. Permanent changes due to nuclear effects on:

a. Aircraft stability and control.

b. Aircraft flight performance parameters (e.g., range, payload, endurance, speed).

c. Maintenance or operational life.

d. The thermal and blast damage effects to material properties should be considered in combination.

e. The efforts shall be a comprehensive analysis considering the above and shall include:

1. Large deformation and partial failure studies (the structure may exceed the yield point of the structural material and take permanent set. The desired load capability of the damage structure is (75 percent) of limit loads).

2. Trade-off studies involving partial damage and reduced performance criteria.

3. New kinds of verification tests or criteria.

4. Recommend design or material changes to accomplish degrees of hardening with their weight and cost trade-offs."

5.1.3 Requirement Limited to Electromagnetic Pulse

"The only nuclear requirement to be considered for the aircraft is the high altitude electromagnetic pulse (EMP) threat. The design should consider possible exposure at any time from hangared states to mission completion. When exposed to the EMP, the aircraft shall be able to complete its mission and effect return and recovery. The approach to achieve the specified levels of EMP hardness shall be described by the bidder. The description shall include the estimation of penalties associated with hardening in terms of weight and costs (RDT&E and production)."

5.1.4 Design Procedure

"The approach for achieving the specified levels of nuclear hardness shall be described by the bidder (contractor). The description shall include the estimation of penalties associated with each hardening technique in terms of weight and costs (RDT&E and production)."

5.2 NUCLEAR BLAST

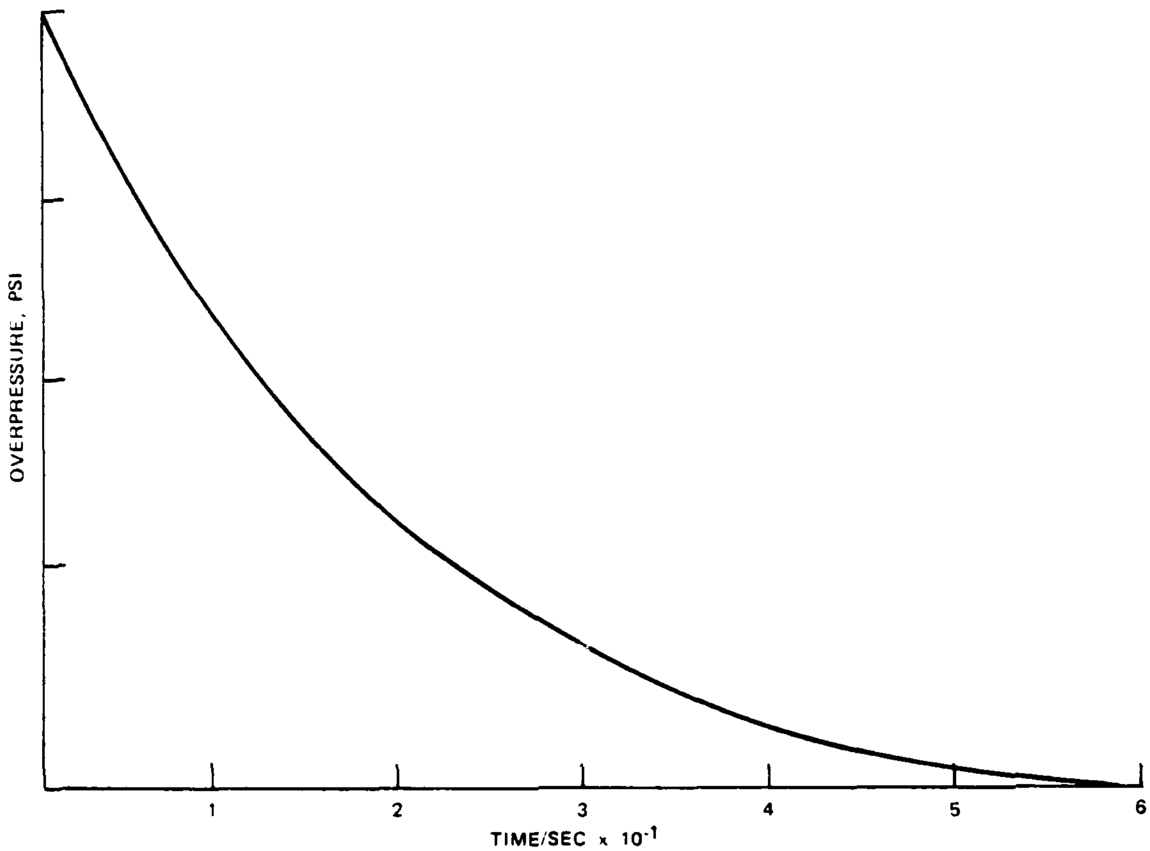
Two types of requirements statements are presented below: a general qualitative statement and a statement which defines quantitatively the blast levels for which protection is to be provided.

5.2.1 Qualitative Requirement

"The aircraft shall be designed to withstand the overpressure and resultant gust effects from the nuclear weapon type and yield in the encounter conditions contained in the statement of work. The aircraft weights, fuel loadings, and weapon loading shall be as specified for the nuclear conflict mission.

5.2.2 Quantitative Requirement

"The aircraft shall effect return and recovery when exposed to ____ repetitions of ____ psi overpressure and associated ____ ft/sec gust for all orientations about the aircraft. The blast environment shall be imposed during maximum maneuvering conditions. Blast and thermal environments will be considered independently. The free field overpressure pulse shape is shown in the following figure. As a goal the aircraft will also complete its assigned mission."



OVERPRESSURE ENVIRONMENT

5.3 THERMAL RADIATION

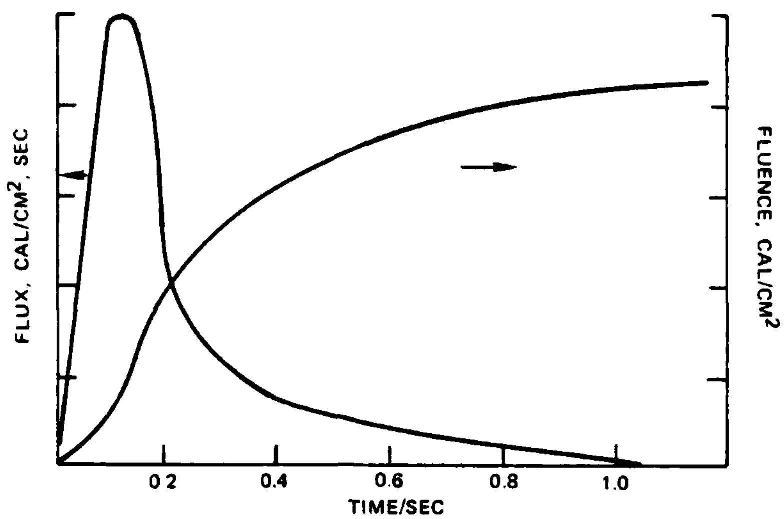
"As with nuclear blast, a general qualitative statement and a more specific example with quantitative requirements are presented.

5.3.1 Qualitative Requirement

"The aircraft structure, crew stations, and external essential components shall be designed to withstand the mission completion level of thermal radiation cited by the S/V specification and statement of work."

5.3.2 Quantitative Requirement

"The aircraft shall effect return and recovery when exposed to ____ repetitions of the free field nuclear thermal flux and fluence environments shown in the following figure. The thermal environment shall be imposed during maximum maneuvering conditions. The thermal environment shall be considered independently from the blast environment and the aircraft shall be allowed to cool between irradiations.



THERMAL RADIATION ENVIRONMENT

The following criteria shall be used to determine absorbed thermal fluence levels:

a. Exterior surfaces (e.g., fuselage, wing, nacelle, control surfaces, firings, etc.) shall be hardened to a thermal fluence of____cal/cm^2 absorbed. The absorbed pulse shape shall be determined from the figure on the previous page using an absorption factor of___.

b. All other exposed components (e.g., radomes, window, antennas, seals, etc.) shall be hardened to the incident thermal pulse specified in the figure. As a goal the aircraft will also complete its assigned mission."

5.4 GAMMA/NEUTRON RADIATION

The example requirements statement is as follows:

"The flight and mission essential electronic components of the aircraft systems and weapon delivery subsystem shall be designed to withstand the levels of gamma and neutron radiation cited by the S/V specification and statement of work. These components shall be hardened so that the functions required for weapon delivery will be intact. Consideration shall be given to means of protecting the crew from radioactive fallout particles. Filtering techniques and positive cockpit pressures shall be considered. Collecting of radioactive particles near the crew or sensitive equipment shall be avoided.

"The aircraft shall effect return and recovery when the electrical and electronic components are exposed to the radiation levels defined in the following table. As a goal the aircraft shall complete its assigned mission."

RADIATION HARDENING REQUIREMENTS

Environment	Requirement
a. Prompt ionizing dose rate* (delivered for $2x10^{-8}$ seconds)	_____rad/sec
b. Delayed ionizing dose rate* (delivered for $2x10^{-6}$ seconds)	_____rad/sec
c. Total equipment ionizing dose	_____rad
d. Neutron fluence*	_____n/cm^{2} (1 Mev Si damage equivalent)

*This environment shall be considered incident on the critical component.

5.5 ELECTROMAGNETIC PULSE

The following electromagnetic pulse requirements statement is presented.

"The aircraft system shall be designed to preclude the failure or malfunction of mission essential electronic equipment from the levels of electromagnetic pulse (EMP) cited by the aircraft S/V specifications and statement of work. Hardening techniques most cost effective for the specific system application shall be selected. The aircraft shall complete its mission and effect return and recovery when exposed to the electromagnetic pulse defined in the following table and figure."

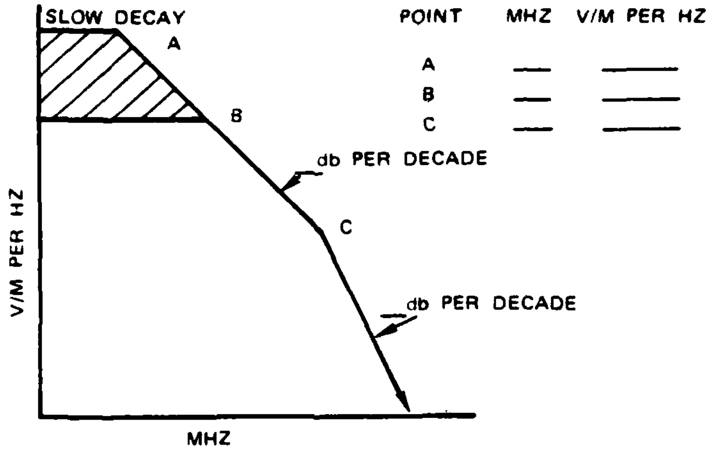
EMP HARDENING REQUIREMENT

Environment*	Requirement
E field	____volts per meter
H field	____amp turns per meter

*Free field environment adjacent to airframe.

Rise time:____seconds to____volts

Decay time: E(τ) =____volts per meter (τ = microseconds)
H(τ) =____ amp turn per meter
B(τ) =____gauss



SPECTRAL DENSITY EMP FIELD

5.5.1 Airframe Hardening

The following paragraph presents a general statement of the requirements for airframe hardening.

"The airframe shall be designed to provide a minimum ____db protection to all components and systems located inside the airframe. Airframe shielding shall be defined as follows:

$$\text{Airframe Shielding (db)} = 20 \log_{10} \frac{\text{Aircraft Skin Current}}{\text{Bulk Cable Current}}$$

over a frequency range of ____MHz to ____MHz."

5.5.2 Cable Hardening

The following paragraph presents a general statement of the requirements for cable hardening.

"Mission critical cable shielding shall be designed to provide a minimum attenuation of db over a frequency of ____MHz to ____MHz. Cable shielding shall be defined as follows:

$$\text{Cable Shielding (db)} = 20 \log_{10} \frac{\text{Bulk Cable Current}}{\text{Any Single Wire Current in Cable}}$$

over a frequency range of ____MHz to ____MHz."

5.5.3 Component Hardening

The following paragraph presents a general statement of the requirements for component (black box) hardening.

"Components shall be designed to withstand the residual EMP induced currents and voltages at each interface connector pin. These residual currents and voltages shall not exceed ____amps or ____volts over the frequency range of ____MHz to ____MHz. In addition, all components shall be designed to meet the requirements of MIL-STD-461."

5.5.4 Deliberate Antennas

The following is a general statement of the requirements for deliberate antennas.

"Components that are connected to deliberate antennas shall be able to withstand volts and amps of EMP induced signals at the components interface."

5.5.5 System Grounding

The following is a general statement of the requirements for system grounding.

"The aircraft shall be designed with a single-point ground for all buses. These include, but are not limited to, the following:

a. Primary and secondary AC power.
b. Primary and secondary DC power.
c. Analog and digital signal buses."

6.0 DHEW EFFECTS PROTECTION

Protection from directed high energy weapon (DHEW or later) effects has not been considered except for very recent aircraft procurements; the specification statements of this section are therefore limited.

Two general statements are as follows:

"The bidder (contractor) shall identify and describe any survivability enhancement features provided against hostile high energy laser weapon effects."

"The aircraft design shall incorporate features that minimize, so far as practical, losses due to high energy lasers (HEL). Design techniques impelemented to reduce nuclear or nonnuclear vulnerability shall not increase aircraft vulnerability to the HEL threat. Design requirements specified for nuclear radiation shall provide system requirements for HEL irradiating___ joules per cm^2 normal to the aircraft skin."

6.1 SUBSYSTEM HARDENING REQUIREMENTS

6.1.1 Fuel Subsystem

"The fuel system (including fuel cells, tanks, lines, pumps, valves, etc.) shall be designed to preclude burn-through or failure of the subsystem for laser irradiation levels up to ___w/cm^2 for___seconds. The fuel system shall be designed to preclude fires that would result in loss of the aircraft from a single irradiation of___w/cm^2 for___seconds."

6.1.2 Propulsion Subsystem

"The fuel accessories of the propulsion system shall be protected to the same level of irradiation as the lines, valves, pumps, etc. or the fuel system. Critical engine sections shall be protected for an irradiation level of___w/cm^2 for___seconds."

6.1.3 Powertrain Subsystems

"Primary rotating shafts shall be designed to survive a laser irradiation level of___ w/cm^2 for___ seconds and retain a design load safety factor of___after the exposure."

6.1.4 Flight Control Subsystem

"The mechanical components of the flight control subsystem shall be designed to survive an irradiation of____w/cm^2 for____seconds. Flight control subsystem electronics components shall be protected from an irradiation of___w/cm^2 for___ seconds."

6.1.5 Fluid Per Subsystem

"The fluid power subsystem shall incorporate high heat tolerant components and lines."

"The subsystem shall be protected against a thermal level of___ joules/cm^2 on components other than fluid lines and___joules/cm^2 on the lines. Protection techniques such as shielding by noncritical or less vulnerable components or structure should be considered."

6.1.6 Electrical Power Subsystem

"Electrical cables for all essential functions shall incorporate a shielding material which will provide thermal protection up to ___joules/cm^2. By-products produced by the heating of these cables shall not present a secondary hazard to personnel."

6.1.7 Structural Subsystem

"All load bearing surfaces shall be designed to carry full maneuvering flight loads after a laser irradiation of____w/cm^2 for____seconds. A minimum maneuvering flight capability of___ g's shall be provided after an irradiation of____w/cm^2 for____ seconds."

6.1.8 Crew Stations

"Canopy materials and barrier materials shall be designed to provide protection for the crew members for a laser irradiation of___ w/cm^2 for___ seconds."

7.0 SURVIVABILITY/VULNERABILITY ASSESSMENT PROCESS

The survivability/vulnerability (S/V) program should include an evaluation and analysis process that culminates in vulnerability and survivability assessments for the system. These assessments are required to support survivability enhancement trade-offs, design studies, and system and subsystem configuration evaluations. The total evaluation process involves an analysis of the mission and the threat, an analysis of flight and mission requirements and essential functions, an analysis of flight and mission requirements and essential functions, an analysis of the ways in which components and subsystems fail and the effect of these failures on the total aircraft system, and the identification of the critical components. The process also includes the analysis of the ways in which the threat can cause damage or failures and the resulting effect of these failures. These analyses support the vulnerability assessment and the subsequent survivability assessments.

The following sections contain representative paragraphs and sample statements for use in aircraft procurements. They represent varying levels of S/V requirements involved in specifying the total S/V assessment process. Each of these representative paragraphs or sample statements is provided to serve as a guideline only, and is to be used only after appropriate tailoring or modification to meet the needs of the specific procurement specification.

7.1 MISSION-THREAT ANALYSIS

"The contractor shall define each operational mode of the aircraft system from takeoff through weapon delivery and landing. The defined mission profiles and hostile threat system shall be analyzed to define the encounter conditions associated with each. These conditions shall be the basis for incorporating survivability enhancement design features and conducting survivability assessment and survivability trade-off studies. Survivability design criteria are expected to be influenced by this effort. The mission description shall contain sufficient detail to provide adequate aircraft configuration factors (weights, center-of-gravity locations, fuel status, armament loadings, etc.), and proposed operational concepts and tactics. The hostile threats shall be categorized for each type of mission employment, and characteristics shall be specified."

7.2 FLIGHT-MISSION REQUIREMENTS AND ESSENTIAL FUNCTIONS

"The requirements and essential functions for flight and mission objectives shall be determined for each mission phase. The flight and mission essential functions shall be established down to the level that individual aircraft subsystems and major components required to perform the function can be identified."

7.3 FAILURE MODE AND EFFECTS ANALYSIS

"The failure mode and effects analysis (FMEA) shall establish the function of each flight-mission critical subsystem, the function of each component of that subsystem, the failure modes of each component in that subsystem, and the effects of each failure mode of that component on that subsystem and on other subsystems."

7.4 ESSENTIAL COMPONENT IDENTIFICATION

"Using the established flight and mission essential functions, each subsystem and major component required to perform each function shall be identified. Subsystem and function redundancies shall also be identified. This shall include degraded modes of operation where such conditions are related to specific kill levels in survivability assessments and for system effectiveness analyses."

7.5 DAMAGE MODE AND EFFECTS ANALYSIS

"A damage mode and effects analysis (DMEA) shall be performed for the specified nonnuclear threats. The failure (response) mode(s) for each essential component shall be identified. The effect of each failure mode upon the essential function(s) of the aircraft system shall be determined, along with the effect upon flight capability or mission completion. It shall include all identified flight and mission essential subsystems and components. Primary and secondary weapon effects, to which each component can be exposed, shall be identified. The type of damage mode that each component can experience (i.e., shattering, jamming, loss of fluid, etc.) shall be identified. The possibility of secondary hazards that may be created by the primary weapon effects (i.e., fire, explosion, toxic fumes, smoke, corrosive materials, etc.) shall be identified. Each nonessential component shall also be examined to determine if a hazardous environment may be created by primary weapon effects. This will also include any cascading effect on other systems from an initial system or component failure. The essential components that may be exposed to the hazardous environments shall be identified."

7.6 VULNERABILITY ASSESSMENT (NONNUCLEAR)

Several vulnerability assessment requirement statements are presented below. They each represent a different level of detail and complexity. The statement used in a procurement should be based on the example(s) which is most compatible with the available data and the required results of the program to be procured.

7.6.1 Computerized Assessment

"The design shall be subjected to a nonnuclear vulnerability assessment. The assessment shall employ the (GIFT, SHOTGEN, FASTGEN) methodology in the development of a target description and the (VAREA, VAREA02, COVART) methodology to determine vulnerable areas. The assessment shall include all identified essential subsystems/components, required kill levels, hostile weapon effects, and attack directions. As a minimum, the following data shall be developed as part of this assessment.

a. Component presented area for each attack direction.

b. Estimated masking or shielding (in equivalent 2024T6 aluminum plate thickness) for each attack direction and threat type.

c. Conditional kill probability ($P_{K/H}$) of each component for each nonnuclear weapon type, and striking velocities from (500 to 3500) ft/sec in increments of (500) ft/sec for projectiles, and (3500 to 9500) ft/sec in (500) ft/sec increments for mission and high explosive projectile fragments.

d. A three-view drawing of the aircraft system (1/10 scale) shall be provided that accurately shows the location and size of each essential component. It shall be in sufficient detail to permit planimetering of component presented area and significant masking and/or armor shielding.

e. The vulnerability of the aircraft system shall be assessed for 26 attack directions. These are for the following azimuth/elevation angles: 0°/0°, 45°/0°, 90°/0°, 135°/0°, 180°/0°, 225°/0°, 270°/0°, 315°/0°, 0°/-45°, 45°/-45°, 90°/-45°, 135°/-45°, 180°/-45°, 225°/-45°, 270°/-45°, 315°/-45°, 0°/+45°, 45°/+45°, 90°/+45°, 135°/+45°, 180°/+45°, 225°/+45°, 270°/+45°, 315°/+45°, 0°/+90°, and 0°/-90°. The vulnerable areas for singly vulnerable and multiply vulnerable components shall be summarized by subsystem and for the total aircraft system for each defined kill category.

f. The man-hours, downtime, and logistic support required for repair of combat damage shall be determined for the specified mission-threat encounter conditions."

7.6.2 Analysis at Limited Aspect Angles

"The contractor shall conduct a nonnuclear vulnerability assessment of the design configuration. The assessment shall determine vulnerability from the six cardinal directions (front, rear, left side, right side, top, and bottom). The single hit vulnerability of the design will be determined for the______kill levels for the following threats:

a.________. . . etc.
b.________

"Vulnerability to projectiles shall be determined at impact velocities from____ft/sec to ____ft/sec in increments of____ ft/sec. For the specified fragment(s), vulnerability shall be determined for impact velocities from____ft/sec to____ft/sec in increments of____ft/sec.

"Each flight (and mission, if applicable) essential component or element shall be identified together with the conditional kill probability ($P_{K/H}$) functions for the specified threat weapons. The rationale (test data, analysis, assumptions), upon which the $P_{K/H}$ functions are based will be provided.

"Each significant masking or shielding element related to the essential items shall be identified and described.

"Vulnerability assessment results will be presented for each of the six aspects defined above.

"A 1/20th scale drawing of the design configuration shall be provided. This drawing shall identify and locate all mission and flight essential components/elements together with all significant masking and shielding. Additional views and sections that clarify special S/V features should also be provided."

7.6.3 Typical Helicopter Vulnerability Assessment

"A vulnerability analysis shall be conducted during the selection of the design configuration. The vulnerability analysis shall be presented in the form of vulnerable area as a function of striking velocity for each threat and each category of kill. The key threats to be considered in this study are 7.62-mm API, 12.7-mm API, 14.5-mm API, 23-mm API and HEI, 30-mm HEI, 37-mm HEI, and 57-mm HEI (Low and mid-intensity threats). The striking velocities shall range from (500 to 3500) ft/sec in (500) ft/sec increments.

"The contractor shall follow the following procedure and methodology in his vulnerability analyses:

a. Target technical description. Detailed information on the construction and operation of all the systems, subsystems and components form the major portion of the target technical description. The description shall include a tabulation of all critical components, listing their title and function along with the failure mode, the cause and the effect of a failure on the component, subsystem, and system. All potential damage mechanisms shall be considered as well as secondary damage effects such as fires, explosions, leaking fluids, etc. Scale drawings (1/10 to 1/4 scale) with dimensions of the aircraft configuration with locations of its major systems and their components shall be used to determine the presented areas of these components for the 18 attack directions (i.e., azimuth/elevation: 0°/0°, 45°/0°, 90°/0°, 135°/0°, 180°/0°, 225°/0°, 270°/0°, 315°/0°, 0°/-45°, 45°/-45°, 90°/-45°, 135°/-45°, 180°/-45°, 225°/-45°, 270°/-45°, 315°/-45°, 0°/-90°). If a computer is used, these drawings will be used to determine the input data for the computer. The drawings shall also provide data concerning the shielding offered to individual target components by other portions of the vehicle. Additional detailed assembly drawings may be required for critical components. The contractor will provide a list of the vital components (regardless of threat for each system which could contribute to each category of kill). Although the primary vulnerability analysis will be conducted for the aircraft in forward flight, the list of vital components should show the level of kill for damage when the helicopter is in a hover mode of flight.

b. Probability of kill given a hit ($P_{K/H}$) for each component. The contractor will assign the $P_{K/H}$'s to all the components and submit the list for approval. The $P_{K/H}$'s should be reviewed and revised periodically and as design changes are incorporated.

c. Presented area (A_p). Once the conditional kill probabilities for each component have been ascertained, it is necessary to reconsider the target technical description to determine component presented areas. One of the least complex and most frequently used means of obtaining presented areas of helicopter components employs a planimeter to measure them from scale drawings made for each of the principal views to be considered. Several computer programs, notably the GIFT program and the SHOTGEN program, have been developed for obtaining presented areas as well as shielding for the components. During this process of obtaining presented areas, it will be necessary to consider the space orientation of the individual components and evaluate the masking or shielding provided to each component by the rest of the helicopter. In general, any shielding provided to a particular component by the rest of the aircraft will be reflected as a reduction in the conditional kill probabilities for that component for all or some of the velocities for a particular view or views. This reduction of conditional kill probability is not arbitrary but based on the residual weight and velocity of the threat after it has perforated the shielding material. A component may be completely shielded for some or all of its presented area for one or more of the views considered. If this occurs, the presented area of the component for these views must be reduced correspondingly. When armor is employed to protect aircraft components, the effect of the armor is analyzed as masking. When the armor is perforated, behind-plate effects will be accounted for, i.e., number, weight, velocity and direction of pieces (for some new types of armor, new firing data will be required).

d. Vulnerable area (A_V). After the conditional kill probabilities have been estimated for the components of the helicopter and the presented areas of these components have been determined, vulnerable areas of these components will be generated.

e. Vulnerability data presentation. Total aircraft vulnerability for all threats, striking velocities, directions, kills, etc., should be considered and presented in a manner which will facilitate evaluation of the net effects obtained by subsequent changes in component size, location, or kill probabilities and protection additions.

7.6.4 Selection of Methodology

If the procurement agency desires the contractor to select the methdology, the following statement may be used as a guideline.

"The vulnerability assessments of the aircraft shall be accomplished using the data resulting from the mission-threat, system description and function, and failure and damage mode and effects analyses. The basic objectives of the vulnerability assessments are to (1) identify deficiencies and evaluate methods and design changes to reduce vulnerability and (2) to provide inputs for the survivability assessment of the aircraft.

"The methodology to be used for the vulnerability assessments shall be selected by the contractor and submitted to the procuring activity for approval. Basic methodologies and associated computer models identified as standards by the JTCG/AS are available. The selected methodology shall provide a means for effective iterative vulnerability assessments during aircraft design, development, and production. It shall provide a tool for use by the applicable service during the operational phase to conduct vulnerability assessments required due to changes in missions, tactics, threats, and aircraft configuration."

7.6.5 Vulnerability Assessment Documentation

The vulnerability assessment documentation should include specific design, analysis, and assessment data so that the procurement agency has a complete understanding of the results and the process by which they were obtained. To achieve this, the procurement specification should include a documentation requirement such as the following:

"The vulnerability assessment report shall contain a summary of the steps performed in the vulnerability assessment. It shall identify and describe the models, computer programs, or manual procedures used in the assessment and identify the appropriate reference documents. There shall be a detailed description of the following assessment elements along with the process used in their development

a. Lethal criteria.
b. Component vulnerability assessments ($P_{K/H}$ values).
c. Failure mode and effects analysis (FMEA).
d. Listing of critical components.
e. Damage mode and effects analysis (DMEA).
f. Quantitative assessment of the accuracy of the FMEA and DMEA.
g. Presented areas (by appropriate aspects).
h. Vulnerable areas (by appropriate aspects).
i. Sources of data used in the assessment.
j. Blast kill contours or volumes.

7.7 VULNERABILITY ASSESSMENT (NUCLEAR)

The following is a representative requirement statement for the assessment of vulnerability to nuclear weapon effects.

"The system shall be subjected to a nuclear vulnerability assessment. It shall be conducted for the nuclear weapon yeild and encounter con·'itions specified in the system statement of work and system specification. The envelopes for each nuclear environmental effect, resulting from defined encounter conditions, shall be plotted for the mission completion, mission kill, and sure kill categories. The assessment shall be conducted using the methodology defined in the aircraft S/V specification and contract statement of work.

"The aircraft design shail be subjected to a detailed dynamic response analysis to determine the (mission completion allowable) response of all mission critical parts, components, subsystems, and systems. For each part, component, subsystem, or system design, the relationship of the (mission completion allowable) response as a function of the nuclear environment of this specification shall be prepared. As a simple example, consider a circuit component in which the (mission completion allowable) response to neutron fluence is a gain degradation of 2 amps. The response of this component to the neutron fluence of this specification will be computed. If the gain degradation from the specified neutron fluence is found to be less than 2 amps, the design meets the specification; if, on the other hand, the gain degradation is found to be more than 2 amps, the design does not meet the specification and it must be redesigned. The contractor will present these data in such a manner so that the procuring agency working group can easily determine that the system design definition meets the S/V specification. The contractor will ensure that the design definition meets the S/V specification before proceeding with the steps defined below.

"The contractor shall perform a system response analysis based upon all of the modes and threat combinations established in the mission-threat analysis. This analysis shall show the (mission completion allowable) levels of each nuclear environmental effect which may be imposed upon the system design by each condition identified in the mission-threat analysis. This analysis shall be performed according to the following itemization.

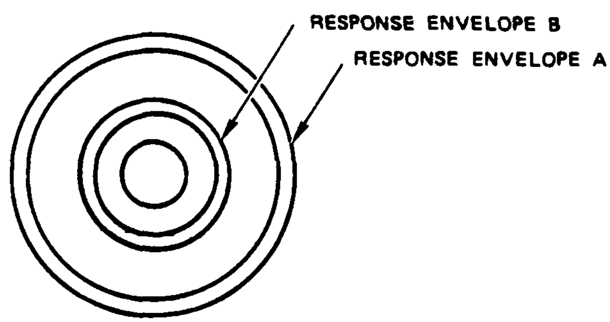
a. Using the actual phenomena pulse shapes associated with the yield, altitude, etc., of each condition, the contractor shall calculate the ranges in all directions from the aircraft system at which detonations can occur and produce the mission completion allowable responses. The envelopes for each nuclear environmental effect determined above shall be plotted on the same figure for each separate yield and altitude combination considered. A minimum of eight range data points equally spaced shall be used to plot each 360° response envelope in each plane. Envelopes shall be provided for at least a top and side view of the system. The nuclear environment produced at the system by weapon detonation at each range data point shall be recorded. Where applicable, phenomena pulse shapes shall be included as a part of the description of the environmental effect.

b. In order to provide insight into the severity of the radiation environment on mission completion, as a separate effort from above, the contractor shall construct envelopes that describe the total whole body radiation dose absorbed by the crew. For each condition of the mission-threat analysis, the contractor shall calculate the ranges in all directions from the aircraft at which detonations can occur and produce six total whole body radiation doses. Detonation orientations, natural aircraft shielding, and parts of the body exposed will be considered in determining the ranges at which the stated values of radiation are actually absorbed by the crew. The procuring agency shall select values of six doses which relate the aircrew mission completion allowable radiation dose levels based upon aircrew task complexity information and aircrew response time histories. The contractor shall then construct envelopes showing the ranges in all directions from the aircraft at which detonations can occur and produce these aircrew mission completion allowable radiation dose levels.

The procuring agency shall review the efforts above to determine if the S/V specifications chosen are sufficient to counter the threat conditions identified in the mission-threat analysis. If the analyses show, in the opinion of the procuring agency, that the system design definition should be altered, the contractor shall propose the two changes in the S/V specifications required to assure:

a. That the greater ranges of the envelopes labeled A in the following figure are reduced so that they more nearly coincide with the ranges of the envelopes labeled B.

b. That the ranges of the envelopes labeled B are increased so that they more nearly coincide with the ranges of the envelopes labeled A.



The procedures used to determine the above changes in the S/V specifications shall be documented in detail.

At the completion of the analyses, the government will choose the nuclear environment design specification for the final production design. After the production drawings are complete, the contractor will repeat the response analyses above on the final production design. In addition to the mission completion allowable responses required, the contractor will provide the envelopes which are associated with system sure-safe, mission-kill, and sure-kill responses for yield/altitude/velocity combinations determined by the procuring agency.

a. The following information supplements the analyses discussed above:

1. The analyses shall, as a minimum, evaluate system avionics (including ship's power, communication, fire control, ECM, etc.), propulsion, air-frame, flight controls, armament, and crew. It shall evaluate the effect of each pertinent nuclear phenomenon on each mission critical part, component, subsystem, and system, to include the nuclear radiation (gamma and neutron, dosages and dose rates, as well as electromagnetic pulse), thermal radiation, overpressure, and gust velocity effects.

2. Attention shall be given to synergistic coupling of component and subsystem responses which may be within allowable responses when calculated individually, but not when coupled (i.e., blast arrival at a heated surface).

3. The analyses shall be conducted for the normal day criteria listed below:

	Normal Day
Ground albedo	0.3
Water vapor pressure (mm Hg)	5
Visibility (miles)	10
Haze layer height (feet)	10000

4. The thermal radiation calculations shall be based upon a camouflage paint surface condition (surface absorptivity 0.92).

7.8 SURVIVABILITY ASSESSMENT

The following is a representative statement of the requirement for a survivability assessment.

"The survivability of the system shall be assessed. The mission-threat data shall be used in conjunction with items such as tactics, mission profiles, maneuverability, detectables, reliability, maintainability, ECM, ECCM, etc.

"The survivability assessment shall be accomplished using: (1) the results of the mission-threat and vulnerability analyses; (2) models of the defense systems; and (3) models of the threat encounter conditions. Survivability assessments provide data that permit determination of the effectiveness of proposed survival enhancement techniques under a variety of threat and encounter conditions. Effectiveness is measured in terms of aircraft attrition and cost factors. The methodology for the survivability assessment shall be as specified in the aircraft systems specification or selected by the contractor and submitted to the procuring activity for approval. Basic methodologies and associated computer models, designated as standard by the JTCG/AS, are available."

7.8.1 Relationship to Missions

The missions for which the aircraft is designed can be related to the survivability assessment through the following:

"As a minimum, the assessment shall include four abbreviated scenarios for each of the developed _____ missions. One scenario for each mission shall correspond to the mission profile identified in the Type Specification, the other three shall be excursions from the basic mission profile. Appropriate threat deployments shall be identified in the S/V specification and approved by the procuring agency.

"Sensitivity analyses that show the effect of varying survival enhancement techniques, attack profile, airspeed, altitude, and threat deployment, shall be conducted for each scenario. As a minimum, for the design configuration and each survival enhancement technique, attack profile, airspeed, altitude, and threat will have two excursions above the baseline and two below, as approved by the procuring agency. All data shall be presented in a format approved by the procuring agency."

7.8.2 Data for Government Analyses

The procuring agency may desire to have survivability assessments performed by the government. If so, there must be data requirements levied on the contractor such as the following:

"The bidders (contractors) shall furnish input data required for this analysis consisting of:

a. The aircraft performance characteristics data furnished to satisfy the performance specifications.

b. Vulnerable area tables.

c. Aircraft signatures (six views – front, sides, top, bottom, and back or at specified azimuth/elevation aspects).

   1. Ultraviolet and infrared – axis curves illustrating the intensity in the 0.1- to 10-micron range, one curve for each view of the aircraft using (1) full military power and (2) afterburners.

   2. Radar – curves illustrating the radar cross-sectional area for each of the views in the C, L, and S bands."

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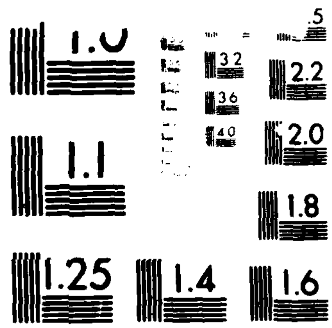
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2.2
32
36
40

8.0 SURVIVAL ENHANCEMENT VERIFICATION

The following specification statements are presented to assist the procuring agency in the development of a verification or quality assurance requirement to demonstrate the effectiveness of survivability enhancement features and the compliance with the survivability/vulnerability (S/V) requirements. Each of these representative paragraphs or sample statements is provided to serve as a guideline only, and is to be used only after appropriate tailoring or modification to meet the needs of the specific procurement specification for survival enhancement verification.

8.1 RESPONSIBILITY

"The contractor shall be responsible for developing the validation plans for system survivability features. They shall be submitted in accordance with the aircraft procurement contract."

8.2 GENERAL REQUIREMENTS STATEMENTS

8.2.1 Detectables

"Tests or analyses shall be performed as required by the S/V specification or statement of work to verify that the specified levels of aircraft detection signatures have been achieved."

8.2.2 Survivability Aids

"Ground or flight tests of the aircraft system survivability aids shall be conducted as required by the S/V specification to demonstrate and verify that their operation is within the specified limits."

8.2.3 Nonnuclear Protection

"Tests and analyses shall be performed, as required by the S/V specification, to verify that nonnuclear protection features comply with required levels. For ballistic protection items, a sufficient number of test shall be performed to provide a high degree of confidence in their results. Where V_{50} ballistic limits are specified for aircrewmen, sufficient testing shall be performed to obtain data sufficient to allow use of V_{50} ballistic limit values with a high confidence level."

8.2.4 Nuclear Protection

"Verifications of nuclear protection levels shall be accomplished by test or analyses as required by the S/V specification and statement of work."

8.3 RELATIONSHIP TO PROGRAM PHASE

"Verification of compliance with nonnuclear (conventional/laser) and nuclear weapon hardening requirements shall be conducted as follows. During the Conceptual Phase developmental testing shall be accomplished, as required, to obtain material response and fuel tankage fire, explosion, and hydraulic ram data to verify the design by analysis. During the Research, Development, Test, and Evaluation (RDT&E) Phase, the qualification category shall be the evaluation for all methods (i.e., test, analysis, etc.); testing during this phase shall be against replica targets to evaluate compliance with design configuration hardness requirements. In the event that the design is inadequate to meet the specification requirements, the contractor is responsible for developing an improved design, and for noting any associated penalties, for inclusion in the product design. During the Production Phase, the qualification category shall be Formal Qualification for all methods (i.e., test, analysis, etc.); testing during this phase shall be against actual system components, unless otherwise specified by the procuring agency. Verification of weapon system hardening shall be accomplished by verification of compliance with specific system hardening requirements."

8.4 VERIFICATION PROCESS

"The following represents the required program which must be accomplished by the contractor:

a. The contractor shall prepare a detailed test plan appropriate for the phase of system development (i.e., conceptual, RDT&E, and production). The plan shall clearly indicate the number of tests to be conducted, schedule, type of threat mechanism(s) being examined, threat mechanism intensity, objective of test (i.e., material response), number of applications of threat mechanism to show statistical validity, etc. The plan shall be approved by the procuring agency; and changes to the schedule shall be made known to the procuring agency sufficiently in advance to permit procuring agency personnel to attend the tests.

b. In support of the vulnerability analysis, the contractor will prepare, conduct and report and test efforts necessary to obtain S/V data on parts, components, and subsystems response which cannot be obtained analytically.

c. Prior to aircraft first flight, tests shall be be conducted on the mission critical final design configurations to verify that the system and subsystem designs meet the test environment associated with the S/V specification.

d. In each of the test/verification efforts of a and b above:

   1. Methods of testing, facilities used, and test instrumentation will be fully documented.

   2. Criteria for establishing failure modes shall be identified.

   3. Procedures for comparing test data with analytical data shall be identified and justified.

   4. All test efforts shall be preceded by an analytical prediction of the results or a fail/pass criteria, and an associated test environment specification to assure that pertinent correlation and interpretation is possible.

5. Test plan documentation procedures and results will be subject to the review of the procuring agency."

8.5 REQUIREMENT VERIFICATION

This section presents a set of qualitative vulnerability requirement verification statements.

8.5.1 Detectables

8.5.1.1 Radar Cross Section. "Compliance with the provisions for radar cross section reduction shall be verified by test and analysis.

8.5.1.2 Infrared Signature. "Compliance with the provisions for infrared signature reduction shall be verified by test and analysis.

8.5.1.3 Visual Signature. "Compliance with the provisions for visual signature reduction shall be verified by test and analysis.

8.5.1.4 Aural Signature. Compliance with the provisions for aural signature reduction shall be verified by test and analysis.

8.5.1.5 Electromagnetic Signature. "Compliance with the provisions for electromagnetic signature reduction shall be verified by test and analysis."

8.5.2 Survivability Aids

"Compliance with the provisions for survivability aids shall be verified by inspection."

8.5.3 Nonnuclear Protection

8.5.3.1 Structure

"Compliance with the nonnuclear hardening requirements specified in ______ shall be verified by test and analysis (number of shots, types, etc.).

8.5.3.2 Aircraft Subsystems

"Compliance with the nonnuclear hardening requirements specified in ______ shall be verified by test and analysis (number of components, shots, threats, etc.)."

8.6 NUCLEAR PROTECTION VERIFICATION

8.6.1 Blast

"Compliance with the gust requirement shall be verified by structural dynamic analysis. Compliance with the overpressure hardening requirement shall be verified by a combination of analysis supported by testing. Test of material specimens shall be conducted to establish strength characteristics and simulated overpressure test of full-scale items shall be conducted to establish dynamic response. Where a method of analysis has been verified by test and is applicable to the design, verification by use of this analysis method without additional testing shall be sufficient."

8.6.2 Thermal Radiation

"Compliance with the thermal hardening requirement shall be verified by a combination of analysis supported by testing to obtain material response characteristics. Where a method of analysis has been verified by test and is applicable to the design, verification by use of this method without additional testing shall be sufficient."

8.6.3 Transient Radiation Effects on Electronics

"Compliance with the transient radiation effects on electronics (TREE) hardening requirement shall be verified by a combination of tests and analyses:

a. Verification by analysis shall consist of review of data resulting from the design hardening effort. These data shall include, where available: (1) component selection criteria, (2) component (circuit piece/part) test data, and (3) circuit analysis results. Additional circuit analysis shall be conducted, if required, to verify compliance with the TREE requirement.

b. In addition to verification by analysis, line replaceable unit (LRU) tests shall be conducted to verify compliance with the TREE hardening requirement during the RDT&E and Production Phases.

c. Compliance with the TREE secondary hazard shall be verified by analysis. This analysis shall show that response to the TREE environment will not prevent return and recovery of the aircraft."

8.6.4 Electromagnetic Pulse Hardening for Electrical and Electronic Equipment

equipment shall be verified as follows:

a. Compilance with the EMP interface pin current requirements shall be verified by a combination of tests and analyses:

   1. Verification by analysis shall consist of review of data resulting from the design hardening effort. These data shall include, where available:

      a. Component test data.
      b. Circuit analysis results.
      c. Description of the application of surge protection devices.

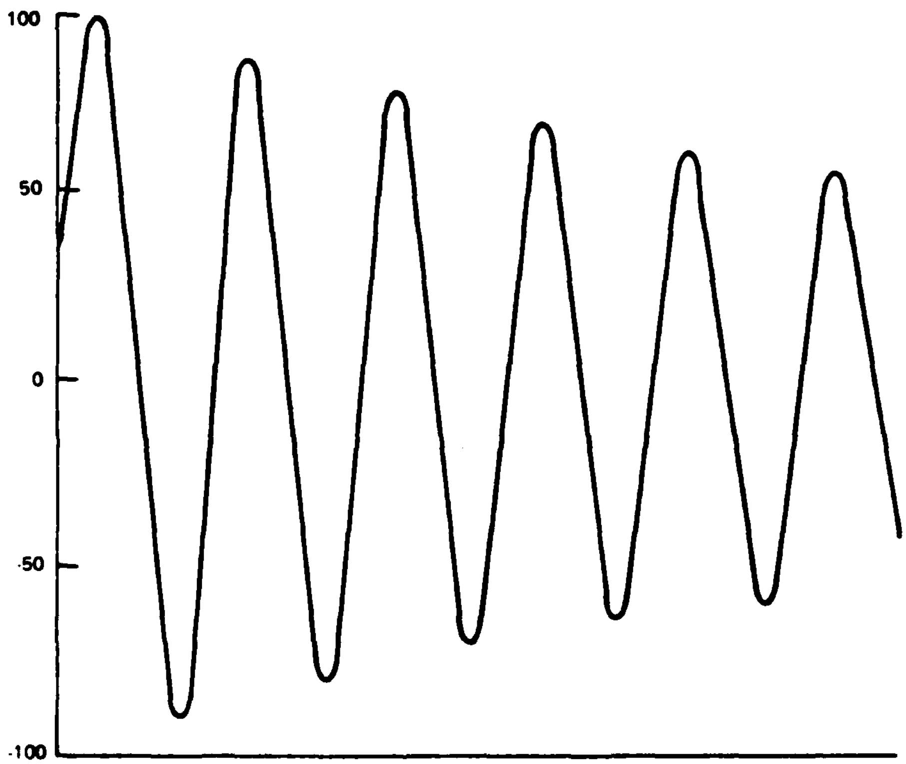
      Additional circuit analysis shall be conducted, if required, to verify compliance with the interface pin current requirement.

   2. Compliance with the EMP interface pin current requirement shall be verified by analysis and a current injection test at each cable interface of essential equipment. The equipment shall be tested in all modes of operation, i.e., switch

positions, with the cables terminated in actual or simulated loads. These tests shall be injected into cables by inductive coupling, from 10 kHz to 30 MHz; above 30 MHz, capacitive coupling may be used. The minimum distance between the pulse generator and the test specimen shall be 3 feet. The shapes of the injected signal shall be a damped sine wave with the characteristics noted in the following figure. The injection frequencies shall be 10 kHz, 100 kHz, 1 MHz, 4 MHz, 10 MHz, 50 MHz, and 100 MHz. One hundred pulses (damped sine waves) 1 second apart shall be applied. Fifty pulses shall have the first half-cycle of one polarity reversed. These pulses shall be applied with the power on and repeated with the power off. It is not required that the currents be injected simultaneously at each interface connector (i.e., the test can be conducted at one interface connector at a time). The test shall show that the design is not vulnerable to the EMP induced interface pin current at or below the specified level.

b. Compliance with the shielding effectiveness requirements for connectors shall be verified by analysis and connector shell tests in a quadraxial test fixture.

c. Compliance with the equipment enclosures requirement shall be verified by an analysis. This analysis shall demonstrate that a voltage of less than 1/4 volt across the longest dimension results from the specified 100 amperes per inch RF currents for the physical dimensions and electromagnetic material characteristics of the enclosure.



INTERFACE PIN CURRENT WAVESHAPE

d. Compliance with the EMP field requirements for electrical and electronic equipment shall be verified by a coupling analysis.

e. Compliance with the deliberate antenna requirement shall be verified by an EMP coupling analysis considering the EMP free-field and adjacent skin currents.

f. Compliance with the EMP secondary hazard requirement shall be verified by analysis. This analysis shall show that response to the EMP environments will not prevent return and recovery of the aircraft.

g. Compliance with the electrical disconnect EMP requirement shall be verified by test in a quadraxial test fixture. Test data that resulted from design-to-effort or level-of-hardness tests and that show compliance with the specified requirement shall be acceptable in lieu of this test.

h. Compliance with the shielding effectiveness requirements for wire bundles shall be verified by analysis testing of the shield in a quadraxial test fixture.

i. Compliance with the EMP shielding effectiveness requirements for door seals and structural joints shall be verified by analysis strip transmission line tests.

j. Compliance of the weapon system for the RDT&E and Production Phases shall be accomplished by a full-field test on an appropriate test range."

8.6.5 Crew Protection from Radioactive Particulate Matter

"Analysis and tests shall be conducted to verify the capability of the particulate filter(s) to satisfactorily filter air contaminated with radioactive particles."

8.6.6 Laser Protection

"Compliance with the high energy laser hardening requirement shall be verified by analysis during the Conceptual Phase: a laser vulnerability assessment model approved by the procuring agency shall be used to conduct the analysis. During the RDT&E and Production Phases, verification shall be by test and analysis. Verification testing shall utilize airflow as specified by the procuring agency."

8.7 TEST PLAN REQUIREMENTS

"The bidder (contractor) shall develop a preliminary S/V program test plan. It shall be divided into two parts, RDT&E and production. The RDT&E testing shall include developmental testing required to obtain design data on survivability enhancement techniques and for evaluation testing of enhancement features where existing test information is not available. The production phase test plan shall include those tests required for complete validation of the S/V design features. Where the RDT&E phase S/V evaluation tests indicate that the required level of enhancement has not been achieved, redesign shall be conducted to obtain the required protection. Cost and weight impacts shall be identified in sufficient detail to permit adequate information for combat effectiveness and life cycle cost analysis. As a minimum, the test plan shall consider nonnuclear and nuclear testing."

8.8 BALLISTIC TESTING REQUIREMENTS

The following set of requirements statements represent a vulnerability verification program for a helicopter procurement. They can be readily adapted to a fixed-wing aircraft procurement by tailoring the system and component references to the aircraft system of the procurement. The threat must also be made to reflect the specific procurement.

8.8.1 Vulnerability Verification

"Component tests and analyses are required to determine aircraft vulnerable areas and to show that the various aircraft systems will meet the required vulnerability. The purpose of this verification program is to determine subsystem and component combat sensitivity and verification of the design and materials to meet the required level of vulnerability. The program shall include ballistic firing, damage tolerance, and controlled damage tests. The test schedule should ensure that the design will meet the required vulnerability and that all necessary design and material changes will be made and qualified prior to production aircraft. These tests shall be conducted on full-size or simulated components (same material and design as the actual components), and on complete subsystems or portions thereof. The vulnerability reduction substantiation, verification, and demonstration tests should be integrated and "piggy-backed" on other existing endurance, fatigue, and failure type test programs to the fullest extent possible. The following is a brief description of the three general types of test and their procedures."

8.8.1.1 Ballistic firing tests. "Ballistic tests shall be conducted to determine if the critical parts of the component are damaged by an impact on the component when armor or other integral shielding is present, and to determine component or specimen failure mode, reaction, and secondary effects as a result of the projectile impact. The "worst" case conditions shall be used for gunfire tests; considering projectile type, projectile orientation (straight-in versus degree of tumble), angle of attack, obliquity, projectile striking velocity, load and speed characteristics, and the most vulnerable location. The gunfire tests shall be conducted with the specified threat and also with more lethal threats, sufficient to determine the component or subsystem total vulnerability. The test should simulate the actual environment in which the component will operate followed by fatigue or endurance tests to failure at typical conditions. The following is the test procedure to be followed to verify that the fuel cell or portion of the fuel cell is ballistically protected against (14.5-mm)(API) projectiles.

a. For fuel cells which are 100 percent protected against (14.5-mm)(API) projectiles, one round shall be fired for each 15 gallons of fuel capacity. A minimum of 4 rounds and a maximum of 10 rounds apply to this test.

b. For fuel cells which are only partially protected against (14.5-mm)(API) projectiles, four rounds shall be fired.

c. When the requirements specify four rounds, two rounds shall be 3/4 to fully tumbled and two rounds shall be fired 90° to cell surface. For additional required rounds, 50 percent of the rounds shall be 3/4 to fully tumbled.

d. At least two of the rounds shall be fired into the corner area, and all rounds shall be fired into the ballistically protected area or for fully protected fuel cells, the rounds shall be fired into the lower 1/4 portion of the cell.

e. The fuel cell shall be filled 2/3 full with Type I fluid and the fuel cell shall be mounted in an actual section of the aircraft structure. There shall be no cause for rejection of a test round (i.e., the causes for rejection of test rounds as stated in MIL-T-27422B are not applicable). A damp seal is required in 2 minutes.

f. This requirement shall be satisfied in addition to the qualification requirements specified in MIL-T-27422B in regard to (50 caliber) (12.7-mm) ballistic testing.

Photographs or movies showing damage, failure modes, etc., shall be obtained and submitted as often as practical to document findings and verifications. Ballistic tests on armor materials shall be performed in accordance with 7-4.2.2.1 of AMCP 706-203.

8.8.1.2 Controlled damage tests. "Controlled damage tests simulate the secondary effects of projectile damage. Where primary damage can be accurately predicted and is not solely responsible for component or subsystem failure, tests shall be conducted without using gunfire to initiate the failure sequence. Typical of these tests are oil leakage rate tests, oil starvation tests, fuel leakage tests, fire probability detection, prevention, adequacy of redundant design, and hydraulic subsystem leakage/redundance adequacy. These tests shall be conducted under the direction of cognizant (offeror) personnel of the particular functional area. Whenever possible, they shall be "piggy-backed" on other endurance, fatigue, or failure test programs.

8.8.1.3 Damage tolerance tests. "Damage tolerance tests shall conform to the following criteria:

a. This type of test shall be used to determine structure type component or specimen failure mode, reaction, and any secondary effects following damage. Simulation of ballistic damage may be used. This type of test is not a substitute for actual qualification but can be used in the early stages of design to verify that the design and material should qualify.

b. The test should simulate the actual environment in which the component will operate followed by static, fatigue, or endurance tests to failure at typical operating conditions.

c. Photographs or movies showing failure modes, etc., shall be obtained and submitted as often as practical to document findings and verifications."

8.8.1.4 Typical Critical Components. "The following is a list of systems with examples of typical critical components which should be subjected, where applicable, to the above design support and verification tests.

a. Fuel system – fuel cells, fittings, pumps, sumps, and ullage inerting or void area protection systems.

b. Control system – rods, bell cranks, mixing units, combining units, actuators, pitch change links, cables, and swashplate.

c. Drive system – tailrotor driveshaft, hangar bearing assemblies, main transmission, gearboxes (nose, intermediate and tail rotor), lubricant sumps, and reservoirs.

d. Support systems – hydraulic power packs, pneumatic subsystem components, wire bundles, fluid lines, generators, and solid state electronic components.

e. Rotor blades and hub assemblies.

f. Crew stations – pilot/copilot seat armor, instrument panel material, canopy, and windshield.

g. Structural – fuselage, tailboom, structural attachment fittings for transmission, gearboxes.

h. Engine installation – mounts, separation structure, and controls.

i. Ammunition feed and storage – ammo magazine, ammo conveyors, and missile pods."

8.8.2 Vulnerability Reduction Demonstrations

"A vulnerability reduction demonstration shall be conducted with a full scale test article to assure that the design concept, configuration, integration of subsystem designs, and subsystem designs meet the RFP requirements. The program shall include:

8.8.2.1 Controlled damage tests. "Controlled damage tests such as final qualification of a gearbox that has lost lubrication operating capability, or dynamic capability of a damaged shaft shall be conducted on the Ground Test Vehicle (GTV).

8.8.2.2 Ballistic firing tests. "Ballistic firing tests or destructive type secondary damage tests shall be conducted on a full scale, realistic mockup. The static test article (STA) shall be modified and prepared for these final system qualification tests. Components for the various subsystems can be previously tested components which are representative of production components (function, size, and strength). This demonstration may be conducted at a government facility and shall be conducted 180 days prior to the start of production.

8.8.2.3 Component selection. "Components shall be selected by determining critical shot lines and analyzing these for several threats (7.62-mm and 12.7-mm API being required, and 14.5-mm API and 23-mm HEI for obtaining further verification of the vulnerability of this design). Additional components shall be included to determine the secondary effects such as jamming, spall, redundance, and separation, shielding, and fire/explosion. Other conditions to be tested are multiple subsystems "kills" by a single projectile and by one subsystem killing another due to close proximity.

8.8.2.4 Operational subsystems test. "There are several subsystems which should be operational because their reaction to ballistic testing might produce effects not otherwise readily determinable from the design drawings. Of primary importance shall be the electrical and hydraulic subsystems. These shall not be total installations but limited to those critical areas where, if a component of these subsystems is impacted by a projectile or fragment, secondary damage and multiple kills could result. Tests which shall be conducted are as follows:

8.8.2.4.1 "Fire/explosion prevention plus hydraulic ram effects – firing typical threat projectiles (7.62-, 12.7-, 14.5-mm API, 23-mm HEI) at fuel tank/structure above and below fuel level under realistic environmental conditions.

8.8.2.4.2 "Crew compartment – firing typical threat projectiles to determine final level of ballistic, spall, and debris protection for the pilot/copilot with all shielding (including armor) and hazardous items in their proper place, simulating items for shielding where practical.

8.8.2.4.3 "Support systems, control system, and engine – firing typical threat projectiles at various hydraulic and electrical system areas to qualify adequate separation of redundant components and prevention of one failed component from destroying a second one.

8.8.2.4.4 "Structural response to internal blast – firing typical threat projectile and simulating with bare charges against critical areas of fuselage, tail boom, and tail pylon.

8.8.2.4.5 "Armor installations – in accordance with 9-12.2.3 of AMCP 706-203.

8.8.2.4.6 "Validation requirements – in accordance with 9-12.2.3 of AMCP 706-203 except that vulnerable area determination and penetration data shall be in accordance with the Survivability Plan."

Appendix A

KEY SPECIFICATION VARIABLES

The specification variables which affect the vulnerability of a given system on an aircraft are generally related to the threat, the aircraft configuration, and the survival criteria. These variables, as applicable to the given system, must be defined and quantified and are as follows:

a. Threat projectile caliber (7.62-mm, 12.7-mm, 14.5-mm, 23-mm, 37-mm, 57-mm, etc.), class [ball, armor piercing (AP), armor piercing incendairy (API), high explosive (HE), high explosive incendiary (HEI), etc.], and model type (identifies materials, component weights) for which protection is required.

b. Fragment threats in terms of weight, dimensions, material, and hardness.

c. Impact velocities for projectiles and fragments.

d. Design impact obliquities.

e. Ballistic protection level and limits (see Appendix B for definitions).

f. Number of projectile or fragment hits for which the system must be designed.

g. Slant range between the aircraft and the ground-based guns.

h. Aircraft velocity vector.

Representative values for the above weapon variables are summarized in Appendix C.

Appendix B

DEFINITION OF TERMS

1. API – armor piercing incendiary projectile.

2. API-T - armor piercing incendiary tracer projectile.

3. Ballistic limit – the striking velocity of a fragment or projectile below which partial (rather than complete) penetrations of the target will predominate. Frequently expressed as a V_X ballistic limit where the "X" subscript denotes the probability of complete penetration for a fragment or projectile of striking velocity "V". For example. V_{05} denotes a velocity at which there will be 5 percent complete penetrations and 95 percent partial penetrations expected for the target material.

4. Ballistic protection – the reduction of vulnerability to threat mechanisms associated with ballistic impacts.

5. Ballistic resistance or ballistic protection level – a measure of the cability of a material or component to stop or reduce the impact velocity and mass of an impacting projectile or fragment.

6. Conditional kill probability – the probability of obtaining a specified level of damage on a target or target element given a hit on the target by a threat mechanism (damage mechanism).

7. Crashworthiness – the ability of an aircraft or aircraft subsystem to survive a crash landing.

8. Damage mechanisms or threat mechanisms – those primary or secondary physical mechanisms generated by a weapon system that may be imposed upon aircraft system. Primary damage mechanisms are those damage or impairment-producing sources directly generated by a threat system. Secondary damage mechanisms are those damage or impairment-producing sources generaged by interaction of an effect of a primary damage mechanism with an aircraft component or element (i.e., fire, smoke, spall, etc.).

9. Damage mode and effects analysis (DMEA) – the analysis of an aircraft system conducted to determine the flight and mission essential components, extent of damage sustained from given levels of hostile weapon damage mechanisms (nonnuclear, nuclear, or high energy laser), and the effects of such damage modes on the continued controlled flight and mission completion capabilities of the aircraft system.

10. Detectables – any aircraft or aircraft subsystem characteristic or signature which can be used to detect, identify, tract, or provide guidance to the aircraft target.

11. Failure mode and effects analysis (FMEA) – a systematic quantified determination of the probabilities and severities of the component, subsystem, and system failures based upon assumed levels of damage and the system operating as an integral part of the aircraft.

12. HEI – high explosive incendiary projectile.

13. HEI-T – high explosive incendiary tracer projectile.

14. Hydraulic ram – the development of shock waves of potential destructive intensity in liquid tanks, components, and lines by the passage of ballistic penetrators through the liquid. The kinetic energy of the penetrator is converted by hydraulic pressure energy in the liquid as the penetrator is slowed by viscous drag.

15. Impact obliquity – the angle between a shot line through a component and the normal vector to the component at the point of shot line intersection.

16. Kill criteria – a measure of the degree to which a target or target element suffers performance degradation due to threat-associated damage mechanisms.

17. Presented area – the area of a target element projected on a plane perpendicular to the attack aspect.

18. Spall – material detached or delaminated in the area surrounding the location or impact with a threat-associated damage mechanism.

19. Survivability – the capability of an aircraft to avoid and withstand a man-made hostile environment without sustaining an impairment of its ability to accomplish its designated mission.

20. Survivability enhancement – any technique, feature, or equipment employed to improve an aircraft's capability of surviving in a man-made hostile environment. This can be through the reduction of detectables, the employment of survivability aids such as countermeasures, or the reduction of vulnerability to the threat weapon damage mechanisms.

21. Susceptibility – the combined characteristics of all of the factors that determine the probability of hit of an aircraft component by a given damage mechanism.

22. Tipping plates – elements of an armor protection system which introduce yaw or tumbling on a projectile to reduce its subsequent penetration capability.

23. Ullage – the volume within a fuel tank above the fuel level; usually a fuel vapor-air mixture.

24. Vulnerable area – a quantitative measure of the ballistic vulnerability of a target or target element expressed in areal dimensions (square feet, square meters, etc.). Typically, vulnerable area is computed as the product of the presented area of the target in a plane normal to the trajectory of the ballistic threat mechanism and the probability of kill of that component given a hit on the target by the ballistic threat mechanism.

25. Vulnerability -- the characteristics of a system that cause it to suffer a finite level of degradation in performing its mission as a result of having been subjected to certain levels of threat mechanism in a man-made hostile environment.

26. Weapon effect – the reaction and interaction between damage mechanisms and the target or target element which result in mission performance degradation.

(Additional survivability related terms are defined in Report JTCG/AS-74-D-002, Proposed MIL-STD-XXX, Aircraft Nonnuclear Survivability/Vulnerability Terms.)

Appendix C

TYPICAL BALLISTIC DATA

The following data are presented to assist in establishing magnitudes and limits on threat weapon variables. Classified threat descriptions should be consulted in the final preparation of specifications.

1. TYPICAL THREAT PROJECTILES

7.62-mm: Soviet 7.62-mm X39 Ball, Short, Type PS
Projectile weight – 122 grains
Core weight – 55 grains (mild steel)
Velocity at 2000 feet – 970 ft/sec*
Muzzle velocity – 2340 ft/sec
*Fired from Ak-47 rifle

Soviet 7.62-mm API, Type B-32 with steel core
Projectile weight – 155 grains
Core weight – 84 grains (mild steel)
Velocity at 2000 feet – 1550 ft/sec
Muzzle velocity – 2880 ft/sec

Chicom 7.62-mm X54R, API, Type 53
(copy of Soviet 7.62-mm API, Type B-32)

U.S. and NATO 7.62-mm AP M61
Velocity at 2000 feet – 1440 ft/sec
Muzzle velocity – 2800 ft/sec

12.7-mm: Soviet 12.7-mm API B-32 or API-T BZT-44
Velocity at 2000 feet – 1880 ft/sec
Muzzle velocity – 2680 ft/sec

14.5-mm: Soviet 14.5-mm API B-32
Velocity at 2000 feet – 2450 ft/sec
Muzzle velocity – 3260 ft/sec

Soviet 14.5-mm API BS-41
Velocity at 2000 feet – 2370 ft/sec
Muzzle velocity – 3280 ft/sec

23-mm: Soviet 23-mm API-T BZT
Projectile weight – 2950 grains
Velocity at 2000 feet – 2320 ft/sec
Muzzle velocity – 3280 ft/sec

Soviet 23-mm HEI-T. Type OFZT with MG-25 fuzing

Soviet 23-mm HEI-T. Super-quick fuzed projectile with A-23 or K-23 fuzing

37-mm: Soviet 37-mm HE-T. Type OR-167 with MG-37 fuzing

[The above data are from AMMRC – Report 73-47, *Ballistic Technology of Lightweight Armor - 1973 (U).*]

Appendix D

KILL CRITERIA

The term kill criteria, or kill level, has been defined as the measure of the degree to which a target or target element suffers performance degradation due to threat-associated damage mechanisms. There are two general categories of kill criteria: those applicable to a nuclear weapon threat and those applicable to nonnuclear weapon threats.

NUCLEAR KILL LEVELS

The following three kill levels have been established to measure the response of the aircraft target or its sub-elements to nuclear weapon effects.

a. Sure-safe – that level of response to nuclear weapon effects where no appreciable damage is sustained, and the aircraft is capable of being refueled and reloaded within the normal turnaround period for operational flight.

b. Mission kill – that level of damage to the aircraft that results in conditions that prevent the mission objectives to be attained, but allows continued controlled flight.

c. Sure kill – that level of damage to the aircraft that causes it to immediately fall out of control.

NONNUCLEAR KILL LEVELS

Attrition Kills

This category covers those aircraft which have sustained combat damage so extensive that it is not reasonable or economical to repair them. The attrition category is divided into five levels of kill. The first four are sequentially inclusive and time dependent. These kill levels are:

a. KK-kill – damage that will cause the aircraft to disintegrate immediately upon being hit. Examples of components which, when damaged, could cause such level of kill would be the structures for both fixed wing (F/W) and rotary wing (R/W) aircraft.

b. K-kill – damage that will cause an aircraft to fall out of manned control within 30 seconds after being hit. Examples of components that when damaged could cause such a level of kill are:

1. F/W – pilot (single), structure, engine (single), ammunition.
2. R/W – pilot, structure, main rotor group, ammunition.

c. A-kill – damage that will cause an aircraft to fall out of manned control within 5 minutes after being hit. Examples of components that when damaged could cause such a level of kill are:

1. F/W – engine, fuel, controls (mechanical or hydraulic).
2. R/W – engine, fuel, controls (mechanical or hydraulic).

d. B-kill – damage that will cause an aircraft to fall out of manned control within 30 minutes after being hit. This category of kill does not apply to rotary wing aircraft. Examples of components that when damaged could cause such a level of kill are:

1. F/W – same as for A-kill plus other engine and fuel system components.
2. R/W – same as for A-kill plus other engine and fuel system components.

e. C-kill – damage that will cause an aircraft to fall out of manned control before completing its mission.

f. E-kill – combat damage that will cause the aircraft to sustain additional levels of damage upon landing and that will make it uneconomical to repair the aircraft as specified by the applicable Technical Orders (TO), Technical Bulletins (TB), and Regulations. Examples of components that when damaged could cause this level of kill are (for fixed wing aircraft) landing gear, flight controls, and control surfaces.

Forced Landing

This category covers those aircraft which as the result of combat damage, are forced to execute a controlled landing (powered or unpowered). This category includes situations where the aircraft damage will require repairs for flight to another area or, if the aircraft cannot be repaired on site, will be recovered by a special team. Examples of components that when damaged could cause such a kill are:

a. F/W – hydraulics, fuel lines, electrical system, engine.

b. R/W – engines (single), main transmission, tail rotor drive (includes gearboxes), control systems.

Mission

This category covers those aircraft which, due to combat damage, cannot complete their designated missions. This category is mission-dependent and has been divided into two levels, mission abort and mission kill.

a. Mission abort – this level covers those aircraft which are not lost to the inventory but, due to combat damage, cannot complete their designated missions.

b. Mission kill – this level covers those aircraft which due to combat damage, fall out of manned control before completing their missions. (This kill is frequently referred to as a C-kill.)

Mission Available

This category covers those aircraft that have landed with combat damage and will require repairs before returning to mission-ready status. There are different levels (intervals) of mission availability which are expressed as MA_X. The subscript "X" is the interval of time which may be expressed in elapsed time, total man-hours, or combinations thereof. This category assumes that the necessary personnel, equipment, and parts are available to perform the repairs.

Appendix E

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ABSTRACT CARD

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This report is intended to provide guidelines for the preparation of procurement specifications for aircraft survivability enhancement equipment, for the survivability/vulnerability (S/V) tasks associated with the procurement of a total aircraft system or its related subsystems, and also for the modification of current fleet aircraft to their related subsystems.

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56. MIL-W-5088. Wiring, Aircraft, Selection and Installation of.

57. MIL-W-13855. Weapon, Small Arms and Aircraft Armament Subsystems, General Specification for.

58. MIL-STD-188. Military Communication System Technical Standards.

59. MIL-STD-461. Electro-Magnetic Interference Characteristics, Requirements for Equipment.

60. MIL-STD-850. Aircrew Station Vision Requirements for Military Aircraft.

61. MIL-STD-890. Environmental Control, Environmental Protection, and Engine Air Bleed Subsystem Analyses.

62. MIL-STD-1288. Aircrew Protection Requirements, Nonnuclear Weapons Threat.

63. MIL-STD-1389. Design Requirements for Standard Hardware Program, Electronic Module.

64. MIL-STD-1511. Inflight Emergency Escape Systems, Aircraft, Requirements for.

65. MIL-STD-1512. Electroexplosive Subsystems, Electronically Initiated, Design Requirements and Test Methods.

66. MIL-STD-1631. Procedure for Selection of Electronic and Electrical Parts During Equipment Design.

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